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Pacific Outer Continental Shelf

OCS Report
MMS 88-0081

Central California Planning Area Geologic Report

U.S. Department of the Interior
MMS Minerals Management Service
Pacific OCS Region

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Central California Planning Area Geologic Report

by

Frank Webster

Deborah J. Burdick

Keith A. Yenne

U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region

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Keith A. Yenne, co-author, passed away on July 3, 1988. We wish to acknowledge his years of dedication to his chosen career. He was a true professional, a gentleman, and a friend.

F. L. Webster
D. J. Burdick

ENGLISH-METRIC CONVERSION

(The following table gives the factors used to convert English units to metric units.)

Multiply English units	by	to obtain metric units
feet	0.3048	meters
statute miles	1.6093	kilometers
nautical (geographic) miles	1.8520	kilometers
inches	2.5400	centimeters
barrels (U.S. petroleum)	0.1589	cubic meters
acres	0.4047	hectares
cubic feet	0.0283	cubic meters

ABBREVIATIONS AND ACRONYMS

API	American Petroleum Institute
bbl	barrel
Cgl	conglomerate
Cht	chert
Co.	Company or county
Diat.	diatomite
Dolo	dolomite
E	east
EEZ	Exclusive Economic Zone
E-log	Electric log
fig.	figure
Grvl	gravel
KOP	kick-off point (drilling)
lat.	latitude
long.	longitude
Mbr	member
Mcf	thousand cubic feet (gas)
Mdst	mudstone
Metaseds	metasediments
N	north
No.	number
OCS	Outer Continental Shelf
Pt.	Point
Qtz	quartz
S	south
Sd	sand
Seds	sediments
Sh	shale
Slt	silt
Sltst	siltstone
Ss	sandstone
Sta. Marg.	Santa Margarita Formation
Std. Cal.	Standard Oil Company of California
TD	total depth (of well)
T&S	Tide and Submerged Lands
UTM	Universal Transverse Mercator
Volc	Volcanics
W	west
w/	with
Zn	Zone
$35^{o}48'$N	35 degrees 48 minutes north (latitude)
$126^{o}35'$W	126 degrees 35 minutes west (longitude)

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INTRODUCTION

This report summarizes the regional geologic framework, exploration history, and hydrocarbon potential of the Central California Planning Area of the Outer Continental Shelf (OCS). It also summarizes the potential geologic hazards that may affect future hydrocarbon exploration and development in the area. This report is prepared as part of the support documentation for Federal OCS Lease Sale 119, tentatively scheduled for late 1990. The discussion focuses upon the petroleum potential of this highly promising area. The Central California Planning Area is a frontier exploration province, portions of which were partially explored by drilling following the May 14, 1963, Federal OCS Lease Sale. This was the first Federal lease sale in the Pacific OCS Region. All of the 1963 leases were relinquished by June 14, 1968, and the well records were made public by the U.S. Geological Survey on December 1, 1974 (appendix 1).

Previous Department of the Interior reports covering this planning area include one on the 1963 Lease Sale (Webster and Yenne, 1987) and others published on the areas proposed for Lease Sale 53 (McCulloch and others, 1977, 1980; Richmond and others, 1981) and Lease Sale 73 (McCulloch, 1980; McCulloch and others, 1982). The Central California Planning area was defined in the final 5-Year Oil and Gas Leasing Program approved by the Secretary of the Interior on July 2, 1987. The Pacific OCS Region is divided into four planning areas, each delineated on official protraction diagrams. These are the Southern California, Central California (fig. 1), Northern California, and Washington-Oregon Planning Areas (Minerals Management Service, 1987).

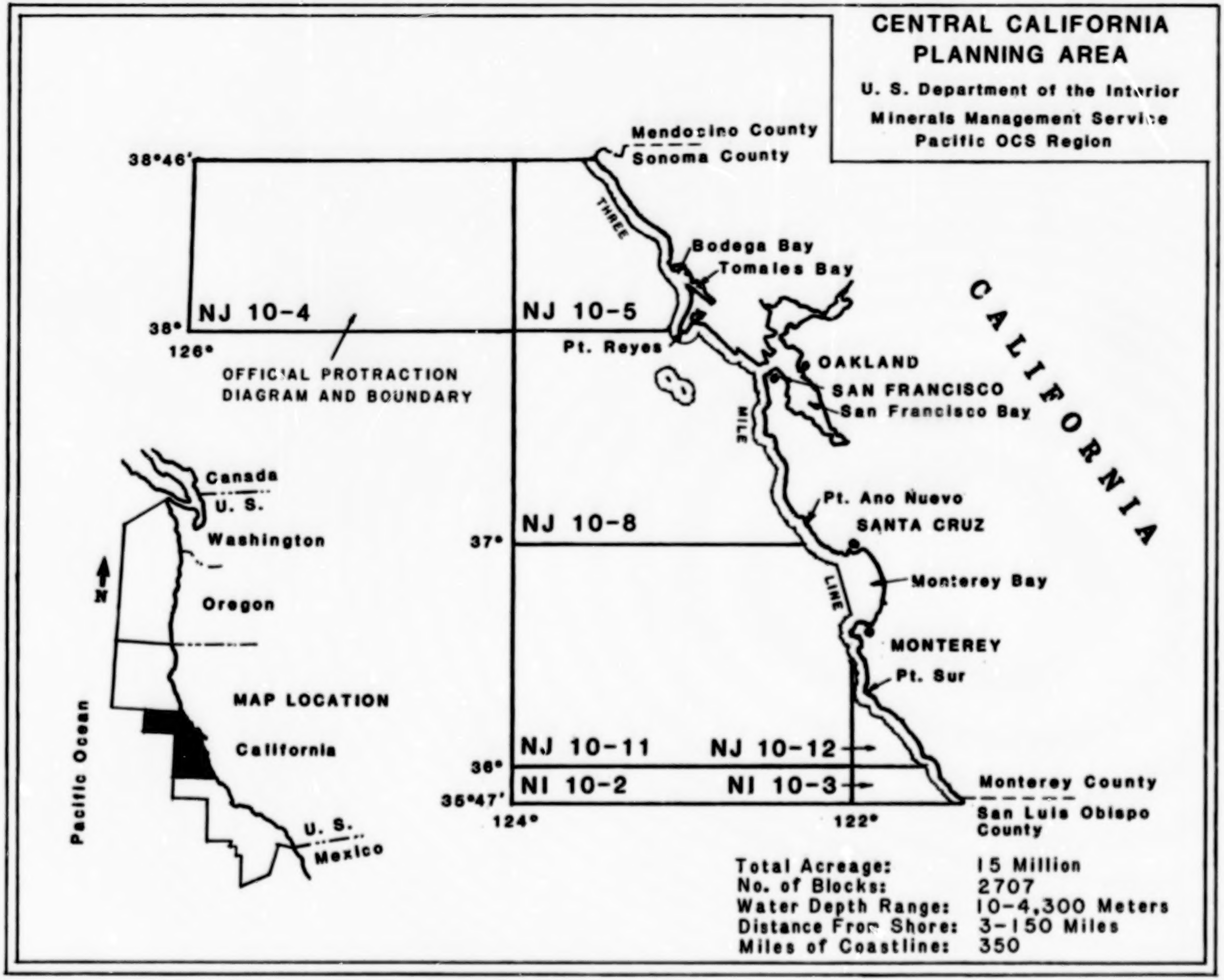

Figure 1. Planning area index.

REGIONAL GEOLOGY

Planning Area

Geography and Physiography

The Central California Planning Area extends about 265 statute miles northward from approximately the Monterey-San Luis Obispo County line to the Mendocino-Sonoma County line (figs. 1 and 2). The planning area is divided into blocks based on the Universal Transverse Mercator (UTM) projection. Each full UTM block is 4,800 meters on a side and encompasses 2,304 hectares. The planning area extends westward as much as 165 miles from the State of California Tide and Submerged Lands (T&S) boundary (U.S. Bureau of Land Management 1976a-f, 1983). The planning area is entirely within the Exclusive Economic Zone (EEZ) established by President Reagan by proclamation in March 1983. The EEZ extends 200 nautical miles seaward from the coastal low-water baseline.

The continental shelf and slope compose less than one-half of the planning area. The remainder is deep ocean basin consisting of portions of the Delgada and Monterey deep sea fan complexes and abyssal plain. The continental shelf extends from the seashore to a depth of approximately 200 meters* (figs. 2 and 3). The area beyond the shelf to

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*Water depths on official charts are given in the International System of Units. One meter equals approximately 3.281 feet.

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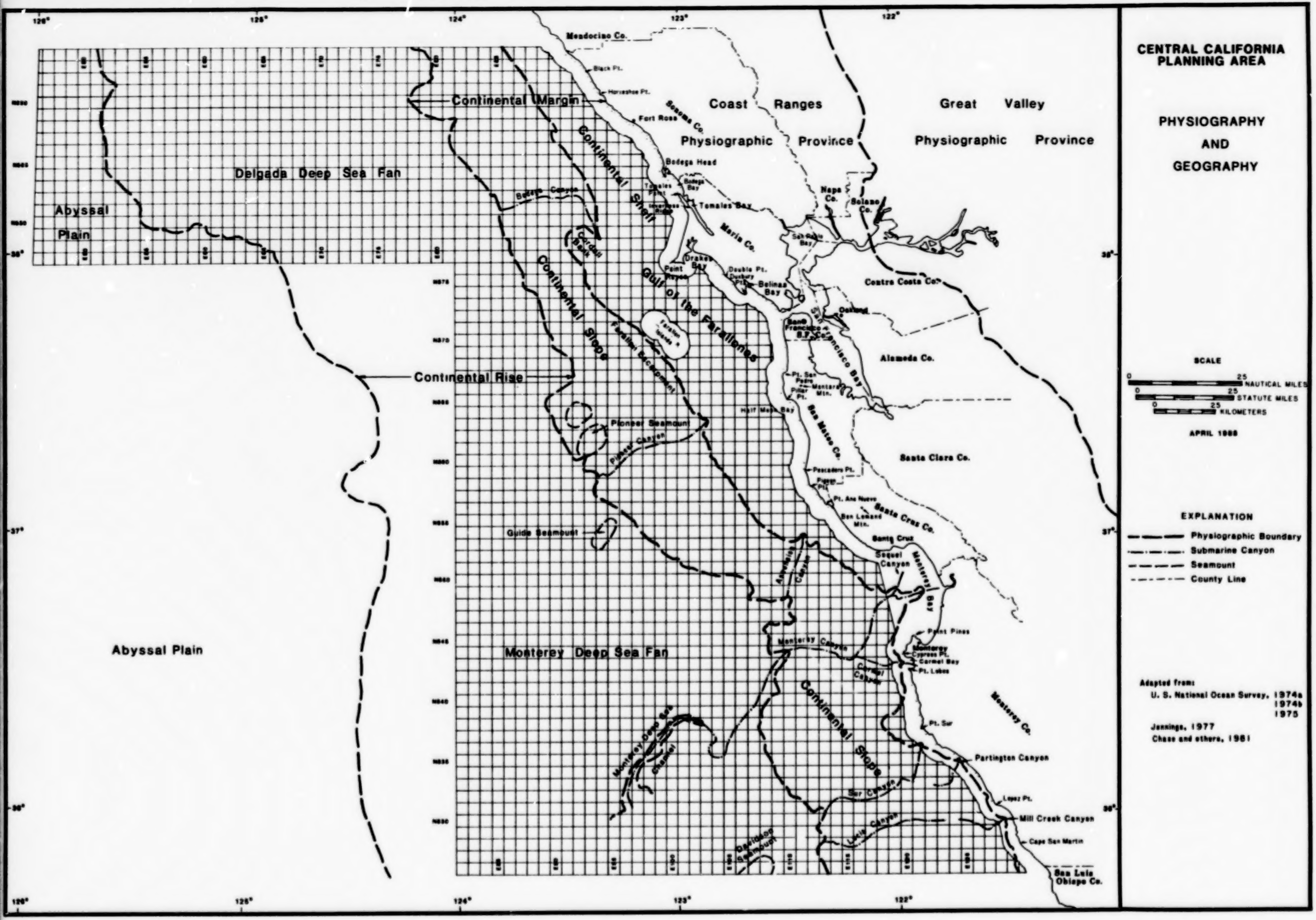

Figure 2. Physiography and geography

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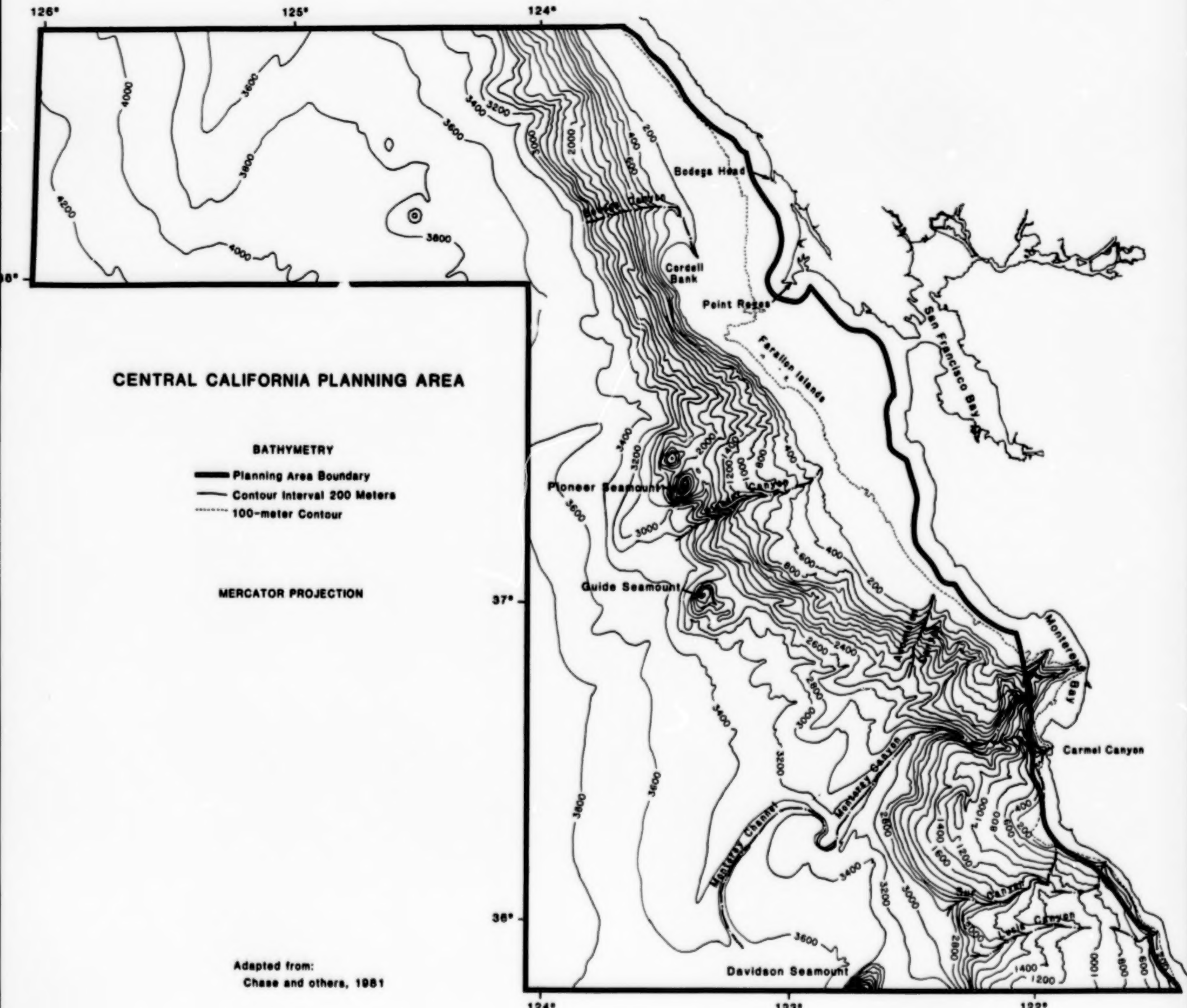

Figure 3. Bathymetry

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approximately 3,000 meters is the continental slope. The width of the shelf varies from about 2 miles in the area south of Point Sur to 27 miles in the area west of San Francisco where it extends westward across the Gulf of the Farallones and the Farallon Islands to the Farallon Escarpment. The escarpment is the uppermost part of the continental slope. The width of the continental slope varies from about 15 miles wide west of Cordell Bank to nearly 50 miles wide west of Cape San Martin. The Cordell Bank is part of the submerged northwestward extension of the Farallon Islands. The Pioneer, Guide, and Davidson volcanic seamounts penetrate upward through the sediments of the lower slope and Monterey Deep Sea Fan (figs. 2 and 3).

The coastline is indented by the Bodega, Tomales, and Bolinas Bays along the trend of the San Andreas fault, and also by Drakes, San Francisco, Half Moon, Ano Nuevo, Monterey, and Carmel Bays. Important headlands in the planning area include, from north to south, Bodega Head, Tomales Point, Point Reyes, Double Point, Duxbury Point, Point San Pedro, Pillar Point, Pescadero Point, Pigeon Point, Point Ano Nuevo, Point Pinos, Cypress Point, Point Lobos, Point Sur, Lopez Point, and Cape San Martin.

The shelf and slope are incised by Bodega, Pioneer, Ascension, Soquel, Monterey, Carmel, Sur, Partington, Mill Creek, and Lucia submarine canyons. Mill Creek Canyon deepens westward to become Lucia Canyon. Monterey Canyon continues as Monterey Deep Sea Channel southwestward across the Monterey submarine fan (U.S. National Ocean Survey, 1974a, b, 1975).

Tectonic and Geologic Setting

The Neogene basins of the Central California Planning Area reflect wrench-fault tectonics associated with the San Andreas transform fault system. The San Andreas fault zone is the approximate boundary between the Pacific crustal plate and the North American crustal plate (fig. 4). In Late Cretaceous time, the Farallon plate, which lay between the converging Pacific and North American plates, was being subducted along the western margin of the North American plate and eventually completely disappeared beneath it. After contact of the Pacific and the North American plates, subduction was replaced by right-lateral, strike-slip faulting resulting from differences in motion of the two plates.

Strike-slip faulting along the San Andreas fault system has displaced a sliver of Sierran-type basement rocks northwestward, possibly by as much as 370 miles, from the southern end of the Sierra Nevada Mountains (McCulloch and others, 1977). These displaced rocks are part of the "Salinian" basement block (Reed and Hollister, 1936) consisting of the Santa Lucia granodiorite and Sur Series metamorphic rocks, which now underlie most of the contental shelf off central California. The Salinian block is flanked on the northeast, across the San Andreas fault zone, by the

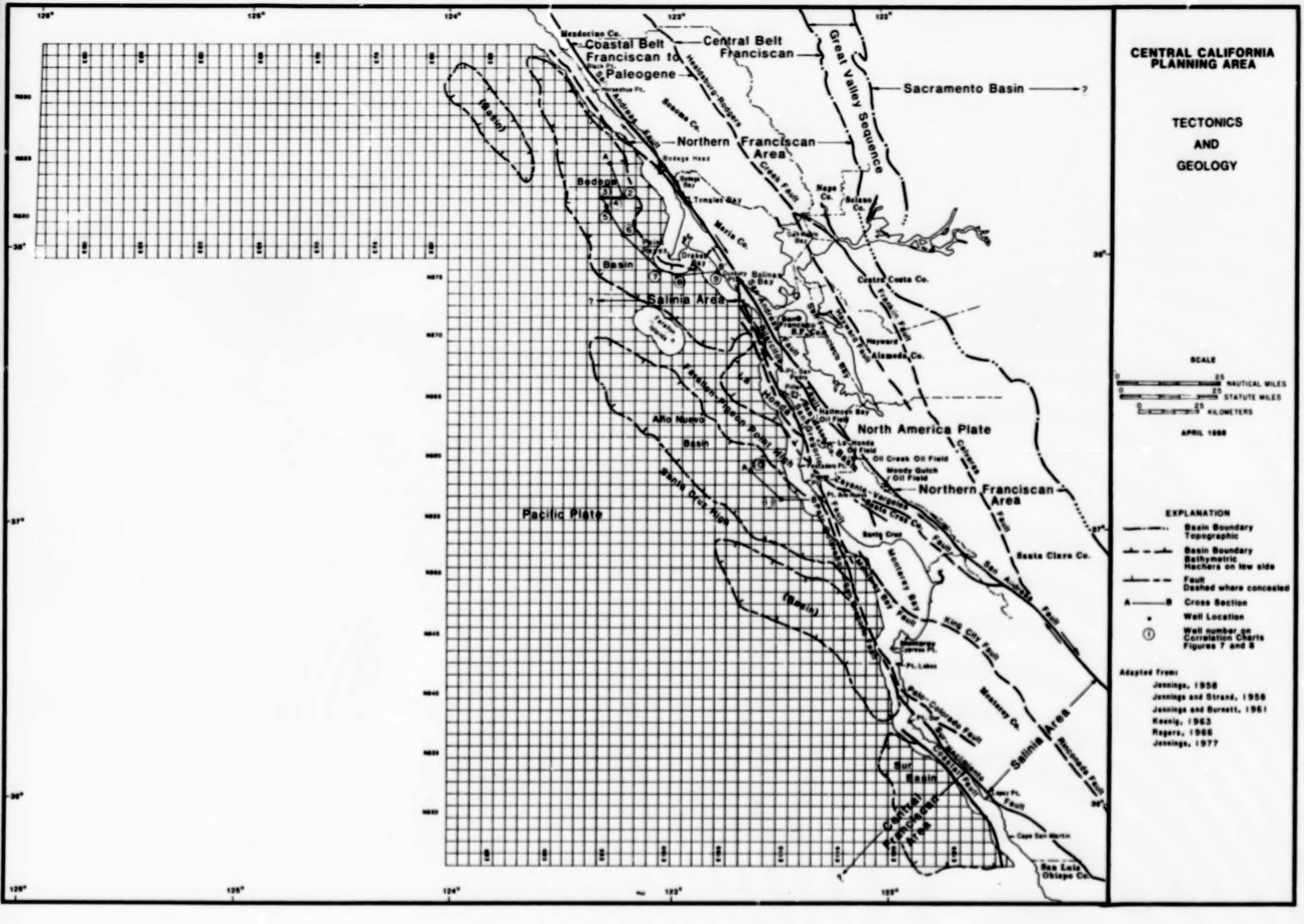

Figure 4. Tectonics and geology

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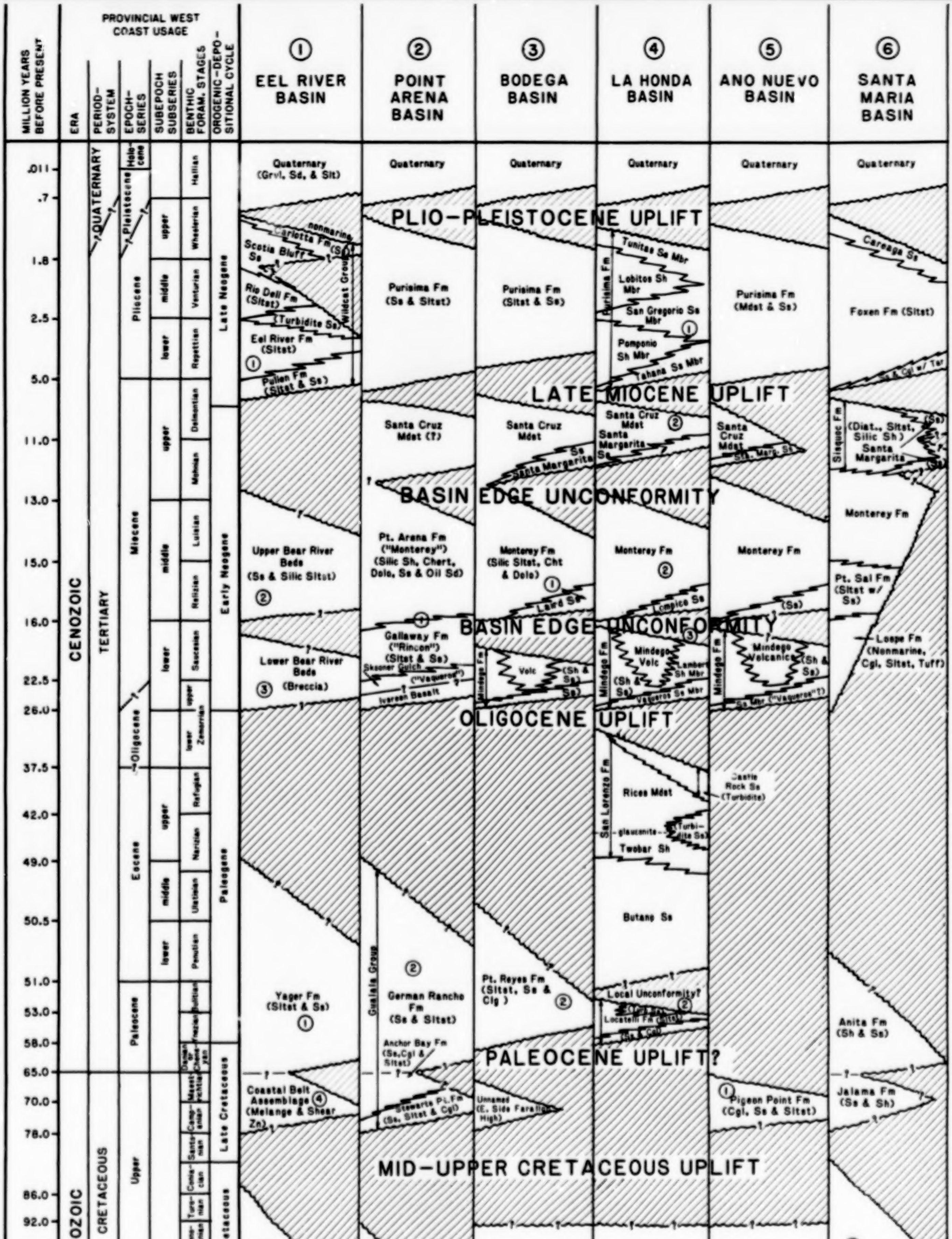
"Northern Franciscan" block of Reed and Hollister (1936) and on the southwest, across the Sur-Nacimiento fault zone, by Reed and Hollister's "Central Franciscan" block (Jennings, 1977). The Franciscan basement rocks consist of a melange of highly deformed or altered sediments and ophiolitic igneous rocks. All three blocks of basement rocks underlie the Central California Planning Area. The composition of the underlying basement rocks controls the structural style and the size, shape, and thickness of hydrocarbon traps. Sediments overlying the Franciscan rocks tend to be extensively deformed, while deformation is less intense over the granitic basement of the Salinian block (Hoskins and Griffiths, 1971; Graham, 1984).

Three major unconformity-bounded depositional/orogenic cycles (sequences), the Paleogene, early Neogene, and late Neogene, make up the Tertiary stratigraphic section of coastal California (fig. 5). Deposition of the Paleogene cycle actually began in latest Cretaceous time and ended, due to regional uplift and erosion, in Oligocene time. Two minor periods of possible uplift and local erosion occurred within the Paleogene cycle during Paleocene and middle Eocene times. Landward transgression of the sea in late Oligocene to early Miocene time initiated the early Neogene depositional cycle. Wide-spread silicic volcanism in early and



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① Ogle, 1953
② Hopps & Horan, 1983
③ Bachman & Crouch, 1987
④ Underwood, 1985
⑤ Bailey et al, 1964

Modified From:
① Weaver, 1944
② Wentworth, 1966
③ Bachman & Crouch, 1987

Modified From:
① Weaver, 1949a,b
② Galloway, 1977

Modified From:
① Cummings et al, 1962
② Brabb et al, 1977
③ Stanley, 1985

Modified From:
① Hall et al, 1959

Modified From:
① Dibblee, 1950

Figure 5. Stratigraphic chart.

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middle Miocene time preceded and was coeval with deposition of siliceous sediments (Bramlette, 1946). Seafloor ridges and low topography on land, combined with increased upwelling at sea, created an environment in which planktonic microorganisms with siliceous or calcareous shells thrived. When these organisms died, they were buried, under anoxic conditions, by a hemipelagic rain of fine-grained terrigenous and organic debris. This detritus formed the banded, fine-grained, richly organic rock of the Monterey Formation.

Renewed orogeny in late Miocene time ended the early Neogene depositional cycle. Rising sea levels in late Miocene time initiated the late Neogene depositional cycle, which ended with late Pliocene-Pleistocene uplift. One or more of these three major depositional cycles may be absent at locations where uplifted areas remained high through succeeding depositional cycles (Webster and others, 1986). Porosity and permeability of the reservoir rocks and the maturation of the source rocks are largely a function of the topographic conditions created by the convergent and transverse plate tectonics of the Pacific coastal basins, which greatly affected the nature of the sediments deposited. The presence of recoverable hydrocarbons depends upon these parameters. High coastal mountains and deep basins nearshore caused sediment transport distances to be short; therefore, sand grains remained angular and were meshed together when deposited, thus diminishing porosity potential. The eroding mountains, which were the source of the sediments, were composed of older metamorphic and crystalline basement rock types, many with low quartz content. The grains composing the sand sediments therefore consisted mostly of unstable minerals that could be converted to clayey materials by heat and pressure. Sediments deposited at river mouths were moved along the coast by longshore currents until intercepted by submarine canyons and then were carried down the canyons by turbidity currents into the deep basins. Depositional loading, as well as tectonic activity, tended to compact the sediments. These factors tended to critically reduce porosity, the reduction generally increasing with depth of burial.

Maturation of the organic material in the sediments requires heat, either associated with deep burial or volcanic activity such as the widespread early Miocene volcanism. Optimum conditions for recovery of hydrocarbons exist when generation and maturation occur with high reservoir porosity. Deep burial of the heterogeneous hard and soft strata of the Monterey Formation sediments by succeeding sediments generated hydrocarbons from the organic material and also caused diagenetic changes from amorphous opaline silica to calcedonic silica and chert in the silica-rich layers. The silica phase transformation released molecular water from the opaline material, causing shrinkage within the layers and creating fracture void space porosity. The change also made the rocks brittle and more susceptible to tectonic fracturing. Subsequent folding and faulting connected the altered siliceous layers by pervasive fracturing, allowing communication of fluids between them, enabling gravity segregation, and increasing fracture porosity greatly (Webster and Yenne, 1987).

Four coastal depositional basins are located within the Central California Planning Area. These are the Bodega basin, La Honda basin (Inner Santa Cruz basin of Hoskins and Griffiths, 1971), Ano Nuevo basin (Outer Santa Cruz basin of Hoskins and Griffiths, 1971), and the Sur basin (also unofficially called the Partington basin, it is the northermost part of the Santa Maria basin) (fig. 4). The names La Honda and Ano Nuevo basins are preferred over the alternative Inner and Outer Santa Cruz basins because "Santa Cruz basin" has been preempted by a topographic basin in the southern California continental borderland. Bodega, La Honda, and Ano Nuevo basins each have as much as 9,000 feet of Tertiary section. Sur basin may have as much as 8,500 feet of sediments.

Additional depositional basins exist in deep water on the continental slope (fig. 4). One of these basins lies off Monterey Bay, southwest of the Santa Cruz High and north of Point Sur. The basin is bisected by Monterey Canyon and incised by canyon tributaries. Maximum thickness of the sediments in this basin may be as much as 7,000 feet, but the section is deeply breached in some areas by channel erosion. Another slope basin lies northwest of Cordell Bank. The sedimentary thickness in this depocenter may also be as much as 7,000 feet.

Due to the lack of geophysical and geological data, the age and lithology of the slope basin sediments are unknown, but they are presumed to be of Neogene age. Deep water, steep slopes, ubiquitous surface slumping, and the lack of present knowledge and technology make these slope basins unattractive exploration targets at this time. Therefore, they are not discussed further in this report.

Bodega Basin

Basement and Late Cretaceous-Paleogene

The Bodega basin is bounded on the west by the Farallon granitic ridge, which extends northward from the Farallon Islands and Cordell Bank. The ridge can be mapped on seismic reflection profiles northward beyond the boundary of the planning area (Silver and others, 1971). The northern boundary of the basin is an uplift near the Mendocino-Sonoma county line; the southern boundary is an arbitrary line extending westward from San Francisco to the south end of the Farallon Islands (Hoskins and Griffiths, 1971).

The geologic boundary between the Bodega and La Honda basins is questionable due to the lack of well and outcrop data between Duxbury Point and Half Moon Bay and due to the stratigraphic differences between the onshore outcrops and wells north of Duxbury Point and those southeast of Half Moon Bay. The possibility of large right-lateral displacement along the San Gregorio fault suggests that the geologic boundary may be at the fault (Clark and others, 1984), thus placing the La Honda basin entirely in State waters and onshore. However, seismic reflection data seem to support the arbitrary boundary westward from San Francisco as suggested by Hoskins and Griffiths (1971). The San Andreas fault borders the Bodega basin on the northeast and continues northward onshore from Fort Ross, going offshore again north of the planning area.

East of the fault, rocks of the Northern Franciscan Area form the basement (Koenig, 1963) (fig. 4). North of Fort Ross, this area contains sediments of the Paleogene and latest Late Cretaceous depositional cycle mixed by pervasive shearing with unfossiliferous Franciscan rocks. South of Fort Ross, the Cretaceous and Paleogene rocks of the Northern Franciscan Area are less plentiful, appearing as remnants overlying or sheared into the melange of Franciscan rocks (fig. 4).

Franciscan rocks exposed in the formation's type area near San Francisco range in age from Late Jurassic (Kimmeridgian-Tithonian) to early Late Cretaceous (Turonian-Coniacian) (Bailey and others, 1964). Mid-Late Cretaceous rocks of Santonian age are absent due to widespread uplift and erosion prior to deposition of latest Cretaceous rocks of Campanian-Maestrichtian age. This unconformity is evident from coastal southern California to central Oregon.

At Black Point, about 32 miles north of Bodega Head and west of the San Andreas fault (fig. 4), spilitic basalt is exposed in the core of an anticline below Cretaceous sediments suggesting a sliver of Franciscan rocks west of the San Andreas fault (Wentworth, 1966; Koenig, 1963). A western branch of the San Andreas fault, extending northwestward from Bodega Head seaward of the coastline, separates the Franciscan basement rocks on the northeast from the Salinian granitic rocks on the southwest.

The northernmost onshore exposure of Salinian basement rocks is at Bodega Head, where it was called "Bodega diorite" and described as biotite diorite by V. C. Osmont in 1904 (Wilmarth, 1938; Keroher, 1966). It was later described as quartz diorite with some gneissoid banding (Koenig, 1963). Other Salinian basement rock outcrops adjoining Bodega basin are at Inverness Ridge, Point Reyes, the Farallon Islands, and Montara Mountain (fig. 2). The Point Reyes exposure is of porphyritic granodiorite. The granodiorite, tonalite, and granite of Inverness Ridge contain inclusions of metasedimentary rocks, schist, and gneiss (Clark and others, 1984).

Onshore, northwest of Fort Ross and west of the San Andreas fault, the Gualala Group rocks consist of sediments ranging in age from the Late Cretaceous (Campanian-Maestrichtian) Anchor Bay and Stewarts Point Formations to German Rancho Formation of Paleocene to possible middle Eocene age (fig. 5, col. 3). The Cretaceous rocks consist of over 8,000 feet of primarily arkosic sandstone and conglomerate, and the German Rancho Formation consists of 10,000 to possibly 20,000 feet of arkosic sandstones, which appear to be deep-water turbidites (Wentworth, 1966).

Outcrops and wells onshore and offshore indicate that the Paleogene to Cretaceous rocks overlying the granitic basement of the Bodega basin consist of conglomerates, sandstones, and siltstones that have been severely truncated by late Paleogene erosion. Late Cretaceous sediments have been sampled on the eastern flank of the Farallon ridge. However, at Point Reyes, in both wells and outcrops, sandstones and conglomerates of the Paleocene Point Reyes Formation overlie the granite and are in turn truncated by Neogene sediments (Galloway, 1977). Paleocene rocks overlying granite also crop out at Point San Pedro, south of San Francisco (Koenig, 1963; Jennings and Burnett, 1961).

More than 1,500 feet of early Paleogene sediments was penetrated by the Tevis well (figs. 4 and 6) drilled onshore near Double Point, and as much as 2,000 feet of early Paleogene deep-water sediments was penetrated in offshore wells in the Bodega basin.

Neogene

Uplift and erosion of the regionally extensive Paleogene depositional basins during late Eocene to Oligocene time preceded the formation of deep localized Neogene basins along the California coast (Blake and others, 1978). Neogene sediments have been sampled onshore in the vicinity of Fort Ross, and rocks of Neogene age are exposed from south of Tomales Point to Duxbury Point. More than 8,000 feet of Neogene rocks was penetrated by the onshore RCA Lockheart well drilled north of Duxbury Point. The Neogene depositional cycle in central California coastal basins began in late Zemorrian time with the deposition of the Mindego Formation, which consists of a basal transgressive sandstone member overlain by a shale member. The formation was contemporaneously intruded by, and interlayered with, a basalt member. This formation is not exposed in outcrop anywhere in the Point Reyes Peninsula area; however, Mindego Volcanics overlying early Paleogene rocks were penetrated in the onshore well at Double Point. In several offshore wells, Zemorrian-age sediments and volcanics unconformably overlie early Paleogene sediments.

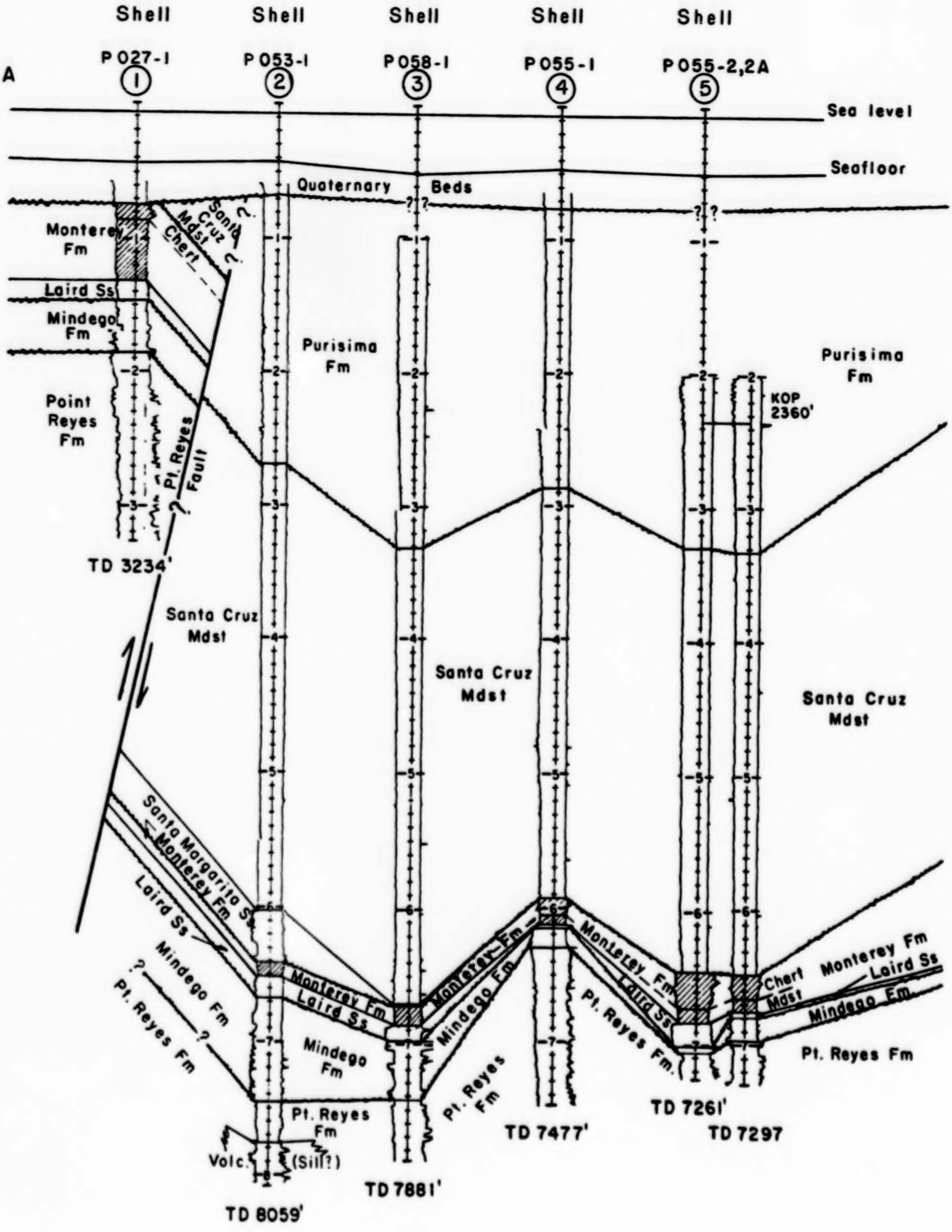

Figure 6. Correlation chart of Bodega basin wells.

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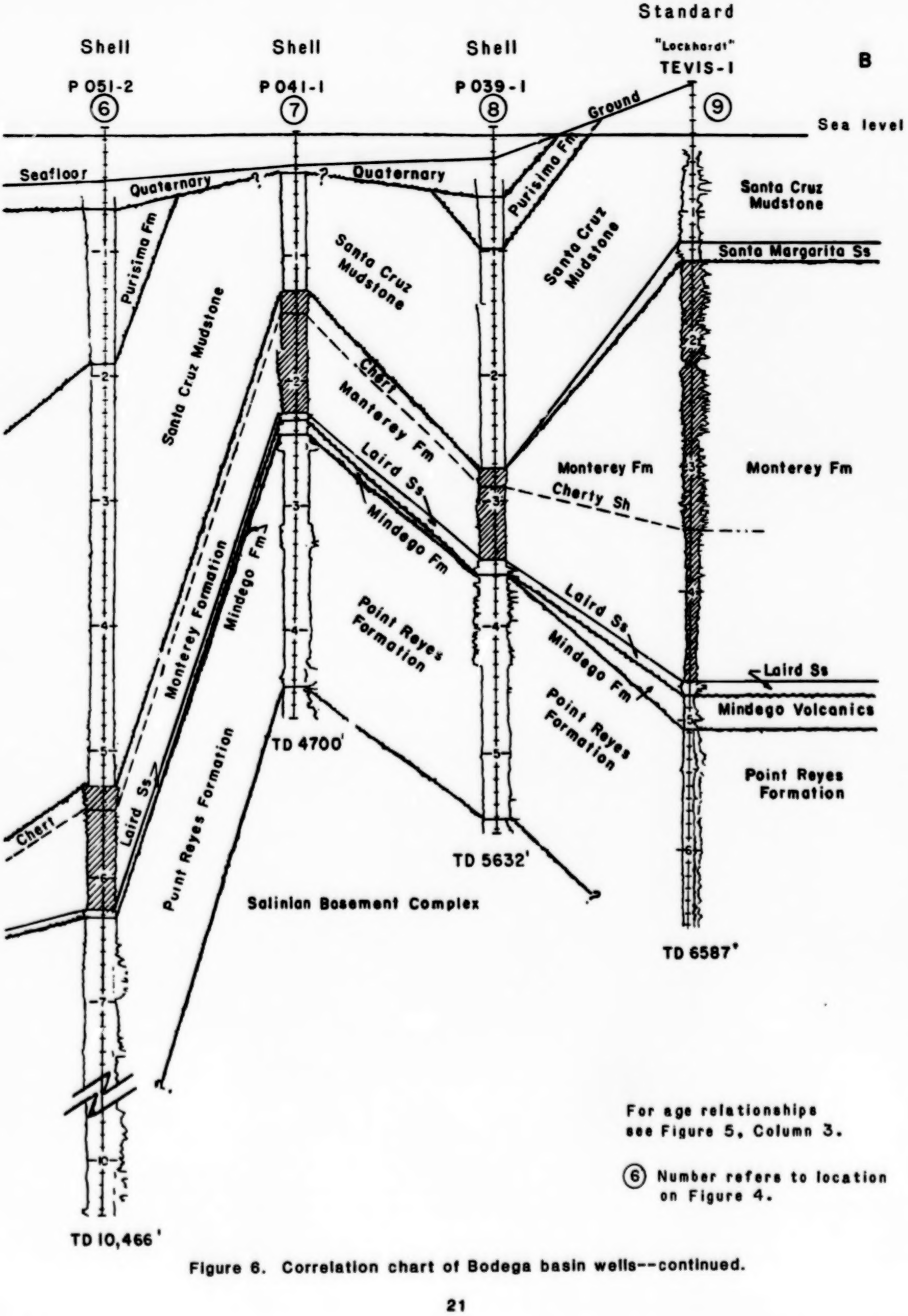

For age relationships
see Figure 5, Column 3.

⑥ Number refers to location
on Figure 4.

Figure 6. Correlation chart of Bodega basin wells--continued.

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In the Bodega and La Honda basins, a depositional/erosional hiatus separates the Monterey Formation from the Mindego Formation (Stanley, 1985), and in many areas the Monterey Formation begins with a basal sandstone, designated the Laird Sandstone in the Point Reyes Peninsula area (Weaver, 1949a, b; Galloway, 1977). The Laird Sandstone is exposed along the west and south sides of Inverness Ridge (fig. 2) where it overlies granitic rocks. In the offshore wells, the Laird Sandstone lies unconformably upon truncated Mindego Formation and in some cases directly upon the Point Reyes Formation. It also overlies Mindego Volcanics in the onshore well at Double Point (figs. 2 and 6). The Monterey Formation is exposed west of Inverness Ridge, extending southeastward to Duxbury Point in the subsurface. As much as 5,000 feet of Monterey Formation was penetrated by the deep well near Duxbury Point. However, it is not present onshore northwest of Drakes Bay, having been truncated by younger sediments (Galloway, 1977). Onshore data indicate that the Monterey Formation thickens to the southeast in the Gulf of the Farallones. Much of the thinning of the Monterey Formation is due to late Miocene uplift and erosional truncation before the deposition of the overlying late Neogene sediments (Clark and others, 1984). Offshore, the thickness varies from less than 200 feet in a well about 12 miles west of Inverness Point to more than 1,000 feet in a well about 3.5 miles southwest of Point

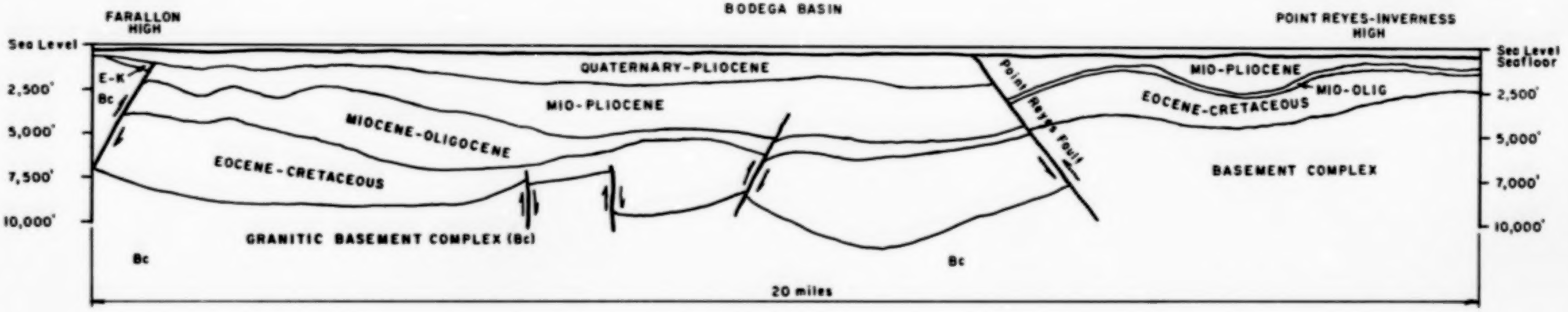
Reyes. The cherty section of the formation is not present in some offshore wells, and the entire formation is absent onshore at Point Reyes. However, the cherty section is well developed in the onshore wells southeast of Drakes Bay (figs. 2 and 6).

The late Neogene rocks generally lie unconformably above the Monterey Formation or upon older rocks. In central California, the late Neogene deposits began with the basal transgressive Santa Margarita Sandstone (Clark and Brabb, 1978; Phillips, 1983; Clark and others, 1984). In deeper waters, the Santa Margarita Sandstone interfingers with and is overlain by the Santa Cruz Mudstone. In the Point Reyes area, these late Neogene units were previously called the Drakes Bay Formation, and in the Double Point to Duxbury Point area, they were called the Monterey Formation (Galloway, 1977).

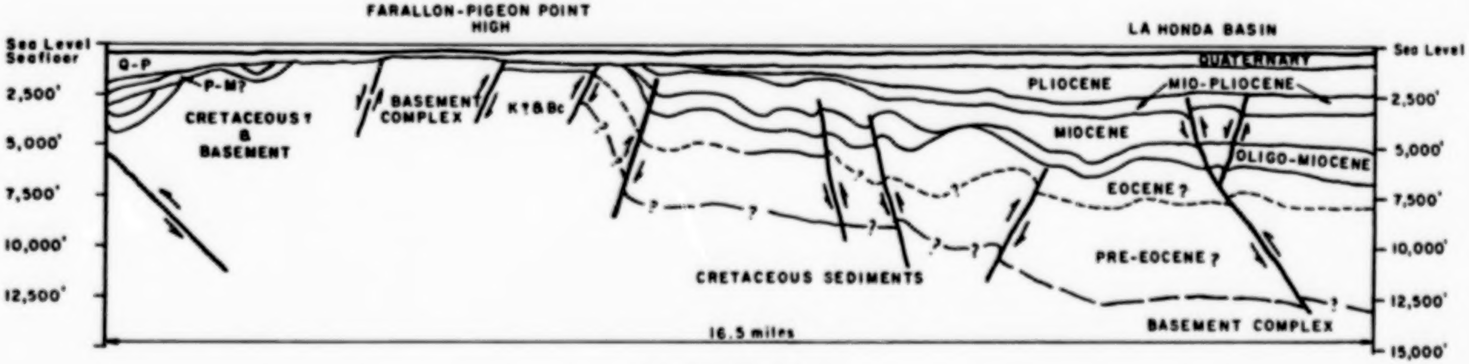
In the Bodega basin, the Santa Margarita Sandstone is exposed at Point Reyes where it overlaps conglomerate of the Paleocene-age Point Reyes Formation and granitic basement rocks. It also is exposed southwest of Inverness Ridge where it unconformably overlies the Monterey Formation. Between the two areas, three shallow wells penetrate the Santa Margarita Sandstone and show it overlying granitic basement rocks. In the Double Point area, about 65 feet of bituminous glauconitic sandstone, cut by bituminous sandstone dikes, separate the Monterey Formation from overlying porcellaneous to less siliceous beds of the Santa Cruz Mudstone. Over 3,400 feet of the Santa Cruz Mudstone is exposed eastward from Duxbury Point. The Santa Cruz Mudstone thins to the northwest where it is overlain by the diatomaceous siltstone and sandstone beds of the Purisima Formation (Clark and others, 1984).

Information from offshore wells shows that the Santa Cruz Mudstone truncates the Monterey Formation by an erosional unconformity. Santa Margarita Sandstone occurs above the Monterey Formation in only two of the wells. These wells are 12 to 15 miles west of Tomales Point, and only the lowermost part of the Monterey beds is preserved beneath the Santa Margarita Sandstone (figs. 2, 4, and 6). In the offshore wells, the Santa Cruz Mudstone-Purisima Formation contact is picked at an electric log marker slightly above the top of the Miocene and may be disconformable in some areas. The upper part of the Purisima Formation is late Pliocene age and is unconformably overlain by Quaternary beds. The Santa Margarita Sandstone ranges in thickness up to 350 feet, the Santa Cruz Mudstone up to 3,400 feet, the Purisima Formation up to 3,100 feet, and the Quaternary beds up to 300 feet.

The structure and generalized stratigraphy of the Bodega basin north of Point Reyes are diagrammatically illustrated on figure 7.



BODEGA BASIN



LA HONDA BASIN

Figure 7. Diagrammatic cross sections of Bodega and La Honda basins

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La Honda Basin

Basement and Late Cretaceous-Paleogene

The onshore La Honda basin, named by Cummings and others (1962), is located west of the San Andreas fault and is underlain by granitic basement of the Salinian block. Metasediments and volcanics of the Northern Franciscan basement block are adjacent to the San Andreas and Pilarcitos faults on the east (Jennings and Burnett, 1961). Paleogene and early Neogene rocks of the La Honda basin are now preserved in outcrop and in the subsurface in an area about 70 miles long and 15 miles wide, parallel to the San Andreas fault, extending from Montara Mountain on the northwest to near San Juan Bautista on the southeast (Stanley, 1985).

The basin is bounded on the southwest by the Ben Lomond-Zayante-Vergeles fault system (Jennings and Burnett, 1961; Rogers, 1966; Jennings and Strand, 1958). Offshore, it is separated from the Bodega basin by a northeast-trending basement high between the coast at San Francisco and the Farallon-Pigeon Point High (fig. 4). The western boundary is the Farallon-Pigeon Point High (fig. 7). However, as mentioned previously, the possibility of large, right-lateral displacement along the San Gregorio-Seal Cove fault system suggests that the geologic boundary with the Bodega basin may be at the Seal Cove fault, placing the La Honda basin entirely in State waters and onshore.

The Locatelli Formation of Paleocene (Ynezian) age is exposed only in three general areas on the flanks of the Ben Lomond Mountain granitic high. On the eastern and western flanks, the Paleocene rocks are successively overlapped by Miocene and younger rocks toward the south. On the northern flank, Eocene rocks of the Butano Formation unconformably overlie the Paleocene sediments, which have paleocurrent features indicating sediment transport to the northeast in the upper part of a submarine fan (Stanley, 1985). The Locatelli Formation consists of arkosic sandstone, mudstone, and conglomerate. Its distribution north of the Ben Lomond and Zayante faults is unknown due to the absence of outcrops and lack of penetration by wells (Stanley, 1985). The relatively uncompacted nature of the Locatelli sediments south of the Zayante and Ben Lomond faults suggests that the area was uplifted shortly after Locatelli deposition and remained high until latest Miocene time.

The Butano Formation, consisting of feldspathic sandstone, mudstone, and conglomerate, represents part of an Eocene submarine fan unconformably overlying the Locatelli Formation and granitic basement rocks. This relationship is exposed along the northernmost edge of Ben Lomond Mountain. There are several large areas of Butano outcrops within the basin, but to the north, at the south flank of Montara Mountain, the Butano Formation is absent and Vaqueros-equivalent sandstones of Oligocene to early Miocene age are in contact with granitic basement. Also, west of the San Gregorio fault north of Pescadero Point, Vaqueros Sandstone and Mindego Volcanics lie unconformably upon rocks of the Pigeon Point Formation of late Cretaceous age. No Eocene rocks are present. Eocene sediments also are exposed between the Pilarcitos and San Andreas faults, where they are in unconformable contact with Franciscan basement rocks (Brabb and others, 1977). Nearly 5,000 feet of sediments of the Butano Formation had been penetrated in wells, and the formation may be as much as 10,000 feet thick (Stanley, 1985).

The San Lorenzo Formation, named in 1906 by Ralph Arnold (Keroher and others, 1966), consists of a lower member, the Twobar Shale, and an upper member, Rices Mudstone (fig. 5, col. 4). The Twobar Shale grades downward into the Butano Formation (Brabb and others, 1977; Cummings and others, 1962). The Twobar Shale is apparently late Narizian in age (Stanley, 1985). The Rices Mudstone member was deposited during the Refugian and early Zemorrian stages and is Eocene to Oligocene in age. It contains beds of glauconitic sandstone with phosphatic pebbles in the basal part, which suggest shoaling. A bioturbated, deep-water sandstone facies occurs in the upper part of the Rices Mudstone unit. It grades laterally and upwardly into turbidite sandstones of the Castle Rock member (designated a unit of the "Vaqueros Sandstone" by Stanley, 1985). In this report, the Castle Rock unit is considered a member of the

San Lorenzo Formation rather than a part of the Vaqueros Formation because the Vaqueros Formation, in its type area, is the basal transgressive sandstone of the Miocene sequence. This association is accepted usage for the Santa Barbara coastal area as well. In most outcrop sections in the La Honda basin, the Castle Rock member is truncated by an Oligocene unconformity, which is above lower Zemorrian rocks and below upper Zemorrian transgressive sandstone members of the Mindego Formation.

Neogene

The earliest Neogene depositional cycle began in the basin center in the La Honda area with deposition of basal transgressive sand and shale, grading to shelf and fluvial deltaic sandstones near the basin edges. These fluvial-deltaic portions of the Vaqueros Sandstone include the Zayante Sandstone and the laterally interfingering and overlying shelf sands of the Laurel Sandstone (Stanley, 1985) (fig. 5, col. 4). These units of the Mindego Formation lie unconformably upon the Castle Rock Sandstone and, in some places, upon the Rices Mudstone of the late Paleogene sequence.

The Lambert Shale interfingers with and overlies the Vaqueros Sandstone units. Interbedded with both the Vaqueros and Lambert members, and also with turbidite sandstones, the Mindego submarine basalt is present over much of the area (Stanley, 1985). Radiometric data have determined the age of the Mindego basalt to be 23-24 million years (Turner, 1970). The above three members together compose the Mindego Formation of late Zemorrian to Saucesian age (Cummings and others, 1962).

The Monterey Formation of the middle Neogene depositional sequence overlies the Mindego Formation. The contact is unconformable at the basin margin where the Lompico basal sandstone member lies upon the Mindego Formation. Basinward, the contact is probably disconformable, with the Lompico absent and a phosphatic pebble conglomerate present above the contact. The sequence rests in angular unconformity on the older lower Miocene, Oligocene to Eocene, and Paleocene sequences, and records a marine transgression of Relizian and Luisian age (Stanley, 1985).

A major episode of uplift, deformation, and erosion early in late Miocene time initiated the late Neogene depositional sequence. The sequence consists of a basal sand; the shallow marine Santa Margarita Sandstone, which is not everywhere present; and the Santa Cruz Mudstone, deposited in deeper water. The age has been established as late Miocene (Stanley, 1985).

The Purisima Formation consists of five alternating sandstone and siltstone or mudstone members (fig. 5). The Tahana sandstone and siltstone member, the lowest unit, conformably overlies the Santa Cruz Mudstone in the western part of the basin but laps eastward unconformably onto the

Monterey Formation (Cummings and others, 1962). This member is overlain by the Pomponio Shale, San Gregorio Sandstone, Lobitos Shale, and Tunitas Sandstone members. Adjacent to the San Andreas fault, the Purisima Formation is unconformably overlain by non-marine beds of the Santa Clara Formation, probably of Quaternary age. West of the San Gregorio fault, it is overlain by the Merced Formation, perhaps the marine equivalent of the Santa Clara Formation (Cummings and others, 1962). Along the sea cliffs the Purisima Formation is cut by marine terraces.

Ano Nuevo Basin

Basement and Late Cretaceous-Paleogene

The Ano Nuevo basin is located west of the San Gregorio fault, which separates it from the Monterey Bay area. It trends northwesterly for nearly 80 miles to about 10 miles west of the Farallon Islands on the continental slope. The basin is approximately 8 miles wide and is bounded on the northeast by the composite Pigeon Point-Farallon High, on the southwest by the Santa Cruz High (Hoskins and Griffiths, 1971), and on the west by an unnamed structural high on the continental slope (fig. 4).

The western boundary of the Salinian basement block is uncertain, although it is known that the Farallon Islands and Monterey Peninsula are composed of granitic rocks. Granite has also been sampled in Monterey and Carmel Canyons, east of the Palo Colorado-San Gregorio fault system

(Greene, 1977). Basement rocks are not exposed west of the San Gregorio fault on the Pigeon Point High and have not been reached in Ano Nuevo basin wells. However, serpentinite and spilitic basalt, found most commonly in Franciscan rocks, have been dredged from the wall of Ascension Canyon below Neogene sediments on the Santa Cruz High (Mullins and Nagel, 1981). Onshore, west of the Sur fault system, serpentinite and sediments of the Central Franciscan basement block are exposed. During the offshore exploration before the 1963 OCS sale, dart sampling recovered asbestos from the seafloor on topographic highs west of Point Sur, suggesting the presence of Franciscan basement.

A topographic lineament extends north-northwest from the Sur fault and merges with the Palo Colorado fault (Jennings, 1958). The Ascension fault extends northwesterly from the Palo Colorado fault parallel to and near the 100-meter bathymetric contour (Mullins and Nagel, 1981; Greene, 1977). These features, or another fault south of the Pigeon Point High within the Ano Nuevo basin, may mark the southwestern boundary of the Salinian granitic basement block.

Onshore at Ano Nuevo Point, sediments and volcanics of early Miocene to Oligocene age lie unconformably upon rocks of the Pigeon Point Formation of late Cretaceous age. Offshore, in the Ano Nuevo basin, exploratory drilling encountered no Eocene rocks between the Oligocene-Miocene rocks and the late Cretaceous sediments present in the wells.

Monterey Canyon tributaries intercept the Santa Cruz High and expose Oligocene, Miocene, and basement rocks, but no Eocene rocks are present. Therefore, Paleogene rocks are probably absent in the basin, although remnants may exist if Paleogene sediments were actually deposited (fig. 8).

Neogene

Basal Vaqueros Sandstone and Mindego Volcanics, overlying Cretaceous sediments, mark the beginning of Neogene deposition west of the San Gregorio fault (fig. 5, col. 5). At Ano Nuevo Point, more than 700 feet of sediments of the Monterey Formation, with a basal sandstone, unconformably overlies Mindego Volcanics exposed in the core of an anticline. At Pescadero Beach on the north side of the Pigeon Point High, shallow marine Vaqueros Sandstone containing the fossil clam "Pecten magnolia" lies unconformably upon Cretaceous sediments and is overlain by Mindego Volcanics.

After drilling through about 1,750 feet of rocks of the Mindego Formation, wells drilled offshore penetrated as much as 400 feet of the Pigeon Point Formation without encountering basement rocks (figs. 4 and 9). The Mindego Formation, of Zemorrian to Saucesian age, consists of diabasic intrusives, tuffaceous and basaltic volcanics, bentonitic clay, siltstone, and sandstone. In the wells, the Mindego Formation was overlain by as much as 3,750 feet of Monterey Formation sediments of Mohnian to Saucesian age.

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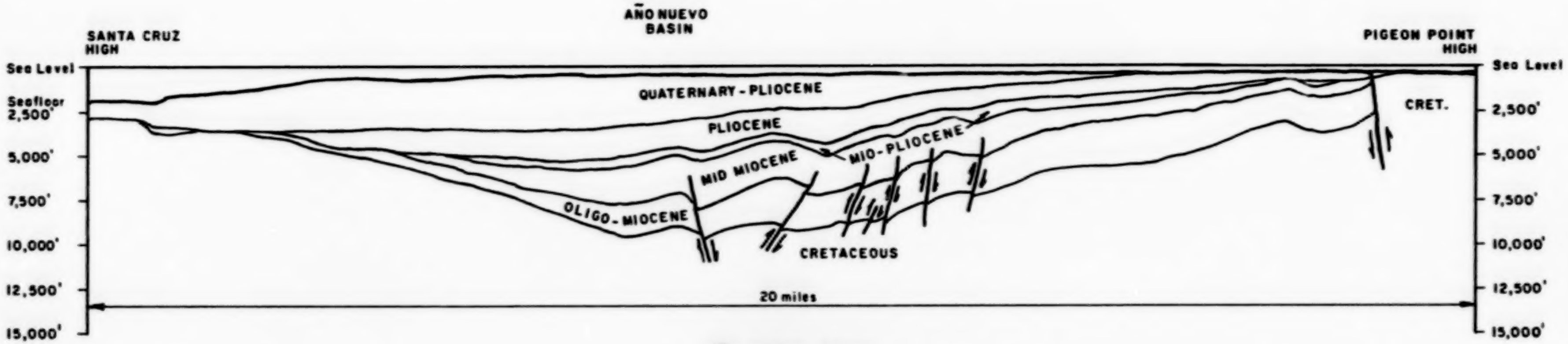
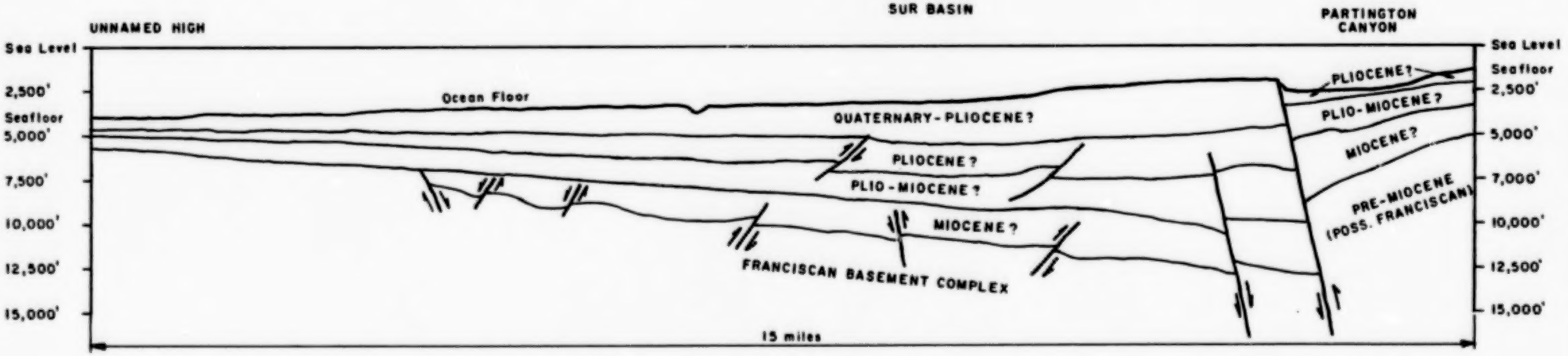


AÑO NUEVO BASIN



SUR BASIN

Figure 8. Diagrammatic cross sections of Año Nuevo and Sur basins

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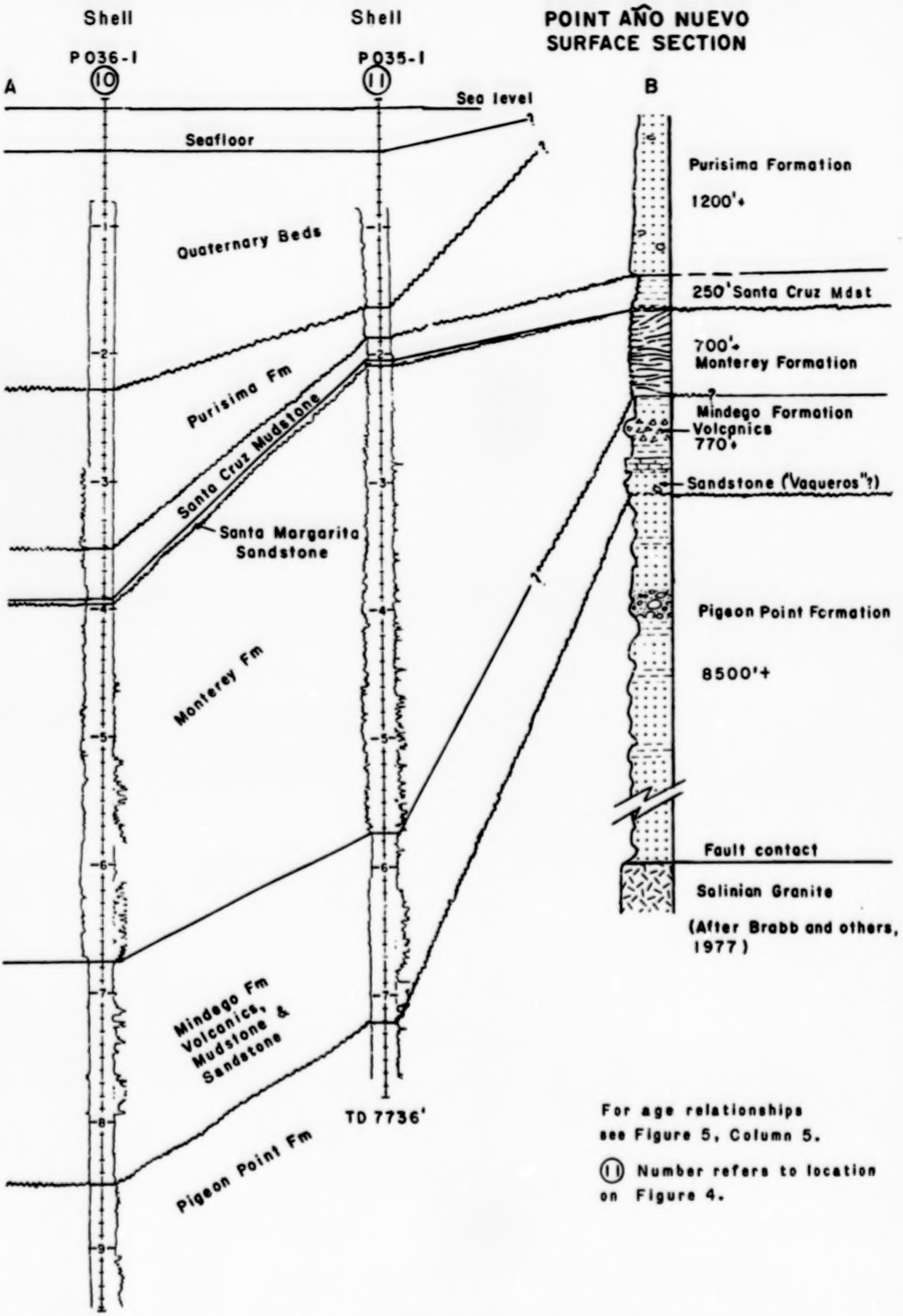

For age relationships see Figure 5, Column 5.

⑪ Number refers to location on Figure 4.

Figure 9. Correlation chart of Año Nuevo basin wells.

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The Monterey Formation consisted of siliceous siltstone, chert, and dolomite, all of which were saturated with tarry oil in the wells.

The Santa Cruz Mudstone, of Delmontian to Repettian age, unconformably overlies the Monterey Formation. A thin, discontinuous Santa Margarita Sandstone often is present at the base of the unit. The Purisima Formation, of Pliocene to Quaternary age, overlies the Santa Cruz Mudstone. In its type area, the Purisima Formation is dominated by sandstones with siltstone interbeds, ranging upward from bathyal near the base to neritic near the top.

Sur Basin

Basement and Late Cretaceous-Paleogene

The Sur basin is the northernmost part of the offshore Santa Maria basin (Blake and others, 1978) (fig. 5, col. 6). It has also been informally referred to as the Partington basin. An unnamed high southwest of Cape San Martin separates it from the rest of Santa Maria basin.

The basin lies west of the Sur-Nacimiento fault zone and is underlain by rocks of the Central Franciscan basement block (fig. 4). It is bounded on the east side by a large coastal fault (Blake and others, 1978). Upper Cretaceous sediments have been mapped onshore in contact with Franciscan rocks in faulted and synclinal areas (Jennings and Strand, 1958), so they probably are present offshore in similar circumstances.

No Paleogene rocks are mapped in the onshore area bordering the Sur basin, and none have been penetrated by wells in the Ano Nuevo basin. However, a few eroded remnants of Paleogene rocks were noted in the wells on the periphery of the southern portion of the Santa Maria basin south of the planning area. These data suggest that Paleogene rocks probably do not exist offshore in the area of the Sur basin.

Neogene

The base of the Neogene sediments, at a depth of greater than 7,500 feet below the seafloor, has been mapped in an area extending from south of Point Sur to south of Cape San Martin beyond the southern boundary of the planning area (Hoskins and Griffiths, 1971). The sedimentary section is generally thin, ranging from less than 2,000 to as much as 8,500 feet at the coastal fault. The section may be composed of thin, discontinuous occurrences of Point Sal and Lospe Formations overlain by less than 2,000 feet of middle and upper Miocene rocks of the Monterey and Sisquoc Formations. Upper Miocene and Pliocene rocks of the Foxen Formation probably compose the greater part of the remainder of the section, overlying and overlapping the Monterey Formation. The sediments are thickest on the east side of the basin, against the coastal fault, suggesting down faulting to form a half-graben (Blake and others, 1978) (fig. 8). Quaternary sediments overlie the sequence.

Bodega and La Honda Basins

Exploration History

In the onshore portion of the Bodega basin, oil sands occur in the Santa Margarita Sandstone at Double Point and farther north. Along the beach to the north, joints and fractures in Monterey Formation are also sometimes oil filled. Oil and gas seeps in the Santa Cruz Mudstone along the beach cliffs north of Duxbury Point attracted wildcatters as early as 1865, when two wells were drilled. Between 1865 and 1954, as many as 14 wells were drilled ranging in depth from 80 to 8,409 feet. None of them were successful, although one was reported to have produced a few barrels per day of low-gravity oil (Galloway, 1977).

Attracted by high-gravity oil seeps from Miocene and Pliocene sediments and heavy oil from terrace deposits, drillers began exploring in the Half Moon Bay area of the onshore La Honda basin in 1867. A number of wells were completed, producing from 25 to as much as 200 barrels per day (appendix 2). The oil was refined locally for its high gasoline content (Crandall, 1943).

The first documented oil-discovery well in the Half Moon Bay area was "Lane's Well," drilled in 1882 or 1884, adjacent to an oil seep in Purisima Creek. Drilling in the Half Moon Bay area continued sporadically until 1979, the later activity spurred by the oil discoveries at Oil Creek and La Honda. County regulations have prevented further drilling in the Half Moon Bay area (Horn, 1983).

In the Half Moon Bay area, the Purisima Formation of Pliocene age truncates the Mindego Formation and, in some areas, lies directly upon Butano Formation of Eocene age. The Monterey Formation is absent locally due to pre-Pliocene erosion.

The Moody Gulch oil field was discovered in the eastern part of the onshore La Honda basin just west of the San Andreas fault in 1878 (California Division of Oil and Gas, 1981) (appendix 2). The field produced high-gravity oil from thin sands in the San Lorenzo Formation in a 10-acre area. Most of the drilling occurred before 1912, and total production exceeded 85,000 barrels by 1921. Little has been produced since then. A major highway now covers the field (Krueger, 1943).

Also in the 1880's, bituminous sands were mined from Santa Margarita Sandstone northwest of the City of Santa Cruz. In 1892, five tar sand quarries were operating in Santa Cruz County. Tar sand production was used primarily for paving materials although some was refined for illuminating oil (Adams and Beatty, 1962).

The Oil Creek oil field was discovered in the onshore La Honda basin in 1955 (appendix 2), producing from the Tony and Costa sands of late Eocene age. Total production to

December 1987 was 202,300 barrels of 43.2° API gravity oil (Fothergill, 1962; California Division of Oil and Gas, 1981, 1987, 1988). La Honda oil field, in the Santa Cruz Mountains of San Mateo County, was discovered in 1956 (appendix 2). Production of 90 to 750 barrels per day of 32.8° API gravity oil was from the upper and lower Costa sands near the top of the Butano Formation of late Eocene age (Fothergill, 1962; California Division of Oil and Gas, 1981). Additional production of 24° oil was found in basal Purisima sands of late Miocene to Pliocene age in 1958 (California Division of Oil and Gas, 1981). Cumulative oil production through December 1987 was 1,335,000 barrels (California Division of Oil and Gas, 1987, 1988).

On May 14, 1963, the first Federal OCS oil and gas lease sale on the Pacific Outer Continental Shelf was held. Thirty-one full and ten partial blocks were offered in the Bodega basin, of which 22 were leased (appendix 1). At that time, blocks were based on the California (Lambert) Plane Coordinate system, and each full block contained 5,760 acres and measured 3 statute miles on a side. No blocks were offered in the offshore La Honda basin. Ten wells were drilled on OCS leases in the Bodega basin from nine locations, all drilled by Shell Oil Company (appendix 3). The following paragraphs on the 10 wells are taken directly from Webster and Yenne, 1987.

The first exploratory well drilled in the Pacific OCS was OCS-P 041 No. 1, about 3.5 miles southwest of Point Reyes in 250 feet of water (appendix 3). Drilling began on September 20, 1963, using the CUSS I, but was stopped by rough weather on October 8 at a depth of 4,401 feet. The hole was reentered on December 3, 1963, using the Glomar II. Santa Cruz Mudstone was penetrated to 1,282 feet, Monterey and Laird Formations to 2,312 feet, Mindego Formation to 2,440 feet, and Point Reyes Formation to 4,475 feet, where the drill encountered granitic basement rocks (fig. 5, col. 3; fig. 6). The well was abandoned on December 13, 1963, at 4,700 feet total depth. Traces of oil staining were observed only in the Miocene rocks below the Monterey Formation and in the Point Reyes Formation of Paleocene age.

Next, OCS-P 051 No. 1 was drilled from the Glomar II about 12 miles to the northwest. The well was spudded on December 22, 1963, in 368 feet of water. After drilling reached 1,170 feet, rough weather forced abandonment of the hole on January 10, 1964. No drill cuttings were recovered and no logs were run. All subsequent wells in the basin were drilled from the Bluewater II. OCS-P 051 No. 2 was drilled about 65 feet southeast of the No. 1 location. It was spudded on August 2, 1964, in 363 feet of water and was abandoned on October 3, 1963, at 10,466 feet total depth (fig. 6). The base of Quaternary sediments was at a depth of 650 feet, and sediments of the Purisima Formation were drilled to a depth of about 1,890 feet. Santa Cruz Mudstone was drilled to 5,272 feet, Monterey Formation to 6,230 feet, Laird Sandstone to 6,330 feet, and Point Reyes Formation to total depth. No shows of hydrocarbons were noted.

OCS-P 055 No. 1 was drilled about 9.5 miles northwest of OCS-P 051 No. 2. Drilling began on October 12, 1964, in 414 feet of water, and the well was abandoned November 6, 1964, at 7,477 feet total depth (fig. 6). The hole penetrated Quaternary beds to 737 feet, Purisima Formation to 2,860 feet, Santa Cruz Mudstone to 5,915 feet, Monterey Formation to 6,138 feet, Laird Sandstone to 6,160 feet, Mindego Formation to 6,303 feet, and Point Reyes Formation to total depth. About 50 feet of Laird Sandstone and Mindego Formation contained thin beds of oil-stained sand.

Next, OCS-P 027 No. 1 was drilled east of the Point Reyes fault about 30 miles northwest of Point Reyes. Drilling began on November 17, 1964, in 348 feet of water, and the well was abandoned on November 29, 1964, at 3,234 feet total depth (fig. 6). The hole penetrated Quaternary sediments to 742 feet, Monterey Formation to 1,308 feet, Laird Sandstone to 1,472 feet, Mindego Formation to 1,872 feet, and Point Reyes Formation to total depth. Shows of tar occurred throughout the Monterey, Laird, and Mindego Formations, with some dead oil in the upper intervals. A weak show was also noted in the Point Reyes Formation. A drill stem test was run in sands in the upper part of the Mindego

Formation, but only drilling mud and water were recovered. No other formation tests were run in wells in the Bodega basin.

OCS-P 053 No. 1 well was then spudded about 4.5 miles northeast of OCS-P 055 No. 1 in 346 feet of water on December 2, 1964. The well was abandoned December 26, 1964, at total depth of 8,059 feet in volcanics, possibly in a dike or sill (fig. 6). Quaternary sediments were drilled to 675 feet, Purisima Formation to 2,682 feet, Santa Cruz Mudstone to 6,035 feet, Santa Margarita Sandstone to 6,395 feet, Monterey Formation to 6,537 feet, Laird Sandstone to 6,660 feet, Mindego Formation to 7,450 feet, and Point Reyes Formation to 7,770 feet where volcanics were encountered. Chert was absent in the Monterey Formation. No hydrocarbon shows were noted.

Shell returned to lease OCS-P 055 to drill No. 2 about 1.5 miles south of No. 1. Drilling began on January 3, 1965, in 421 feet of water, and the well was abandoned on January 23, 1965, at 7,261 feet total depth in Point Reyes Formation (fig. 6). The Purisima Formation-Santa Cruz Mudstone contact was at 3,295 feet, top of Monterey Formation at 6,450 feet, top of Laird Sandstone at 6,822 feet, Mindego Formation at 7,000 feet, and Point Reyes Formation at 7,060 feet. Oil stains and traces of bleeding oil were noted from 6,480 to 6,590 feet in Monterey chert, and oil fluorescence was noted from 6,700 to 6,745 feet in shales of the Monterey Formation.

On January 24, 1965, the well was redrilled as OCS-P 055 No. 2A. The kickoff point for the new hole was at 2,360 feet. The hole was directed northwesterly from the surface location by turbo-drill and drilled to 7,297 feet before it was abandoned in Point Reyes Formation on February 3, 1965 (fig. 6). The section penetrated was Purisima Formation to 3,317 feet, Santa Cruz Mudstone to 6,477 feet, Monterey Formation to 6,742 feet, Laird Sandstone to 6,778 feet, Mindego Formation to 6,970 feet, and Point Reyes Formation to total depth. Oil staining, odor, fluorescence, and some bleeding oil were noted in chert of the Monterey Formation from 6,490 to 6,650 feet.

The drilling vessel was then moved back to Point Reyes to spud OCS-P 039 No. 1, 3.5 miles due south of the Point, on February 16, 1965 (fig. 6). The well spudded in Quaternary sediments and penetrated sediments of the Purisima Formation from 532 feet to 990 feet, Santa Cruz Mudstone to 2,730 feet, Monterey Formation to 3,470 feet, Laird Sandstone to 3,560 feet, and Point Reyes Formation to 5,535 feet, where the drill encountered granitic basement rocks. The hole was abandoned at 5,632 feet on March 3, 1965. No hydrocarbon shows were noted.

The last well drilled, OCS-P 058 No. 1, about 2.5 miles northwest of OCS-P 055 No. 1, was spudded on January 18, 1967, in 440 feet of water. The well was abandoned February 5, 1967, at 7,881 feet (fig. 6). It spudded in Quaternary sediments at 508 feet and penetrated beds of the Purisima Formation from about 750 feet to 3,317 feet. Sediments of the Santa Cruz Mudstone were drilled to 6,710 feet and Santa Margarita Sandstone to 6,728 feet. The Monterey Formation, with the chert member missing, was penetrated from 6,728 to 6,872 feet, Laird Sandstone to 6,992 feet, Mindego sediments and volcanics to 7,430 feet, and Point Reyes Formation to total depth. Oil stains and hydrocarbon fluorescence were noted from 6,700 to 6,800 feet in the Monterey Formation.

No wells were drilled in offshore La Honda basin (fig. 5, col. 4).

Hydrocarbon Potential

Although the richest source rocks of the Bodega and La Honda basins are in the Monterey Formation of middle and early late Miocene age, other formations with fair to excellent source rock potential are present throughout the area. The Santa Cruz Mudstone of late Miocene to early Pliocene age is very similar in lithology to the Monterey Formation and has abundant oil indications onshore from Bolinas to

Double Point. It also appears to be the source for oil in the Santa Margarita Sandstone northwest of the City of Santa Cruz as well as at Double Point.

The Lambert Shale member of the Mindego Formation is lithologically similar to the Twobar Shale and Rices Mudstone members of the San Lorenzo Formation of late Eocene to Oligocene age. These units, along with shale interbeds in the upper part of the Butano Formation, are the most likely source rocks for the oil production in the La Honda, Oil Creek, and Moody Gulch fields. The Monterey Formation and the Santa Cruz Mudstone, as well as the Eocene-Oligocene units listed above, probably also contributed to production in the Half Moon Bay and Bolinas areas.

Sandstone reservoirs in the Paleogene section, the "Vaqueros-equivalent" sandstone members of the Mindego Formation, the Laird-Lompico Sandstones at the base of the Monterey Formation, and the Santa Margarita Sandstone below the Santa Cruz Mudstone are all potential sandstone reservoirs in the Bodega and La Honda basins. The fractured rocks of the Monterey Formation are the best source rocks and may have the best reservoir potential as well.

Ano Nuevo Basin

Exploration History

The existence of oil fields in the La Honda basin and tar sands overlying granitic basement rocks west of Ben Lomond Mountain suggested possible hydrocarbon production to the west across the San Gregorio fault. From outcrops of the Monterey Formation at Ano Nuevo Point, a rainbow sheen of petroleum colors occasionally appears on the sea and laps upon the shoreline, indicating the possibility of seeps and oil generation in the Ano Nuevo basin. Quartz sand in the Santa Margarita Sandstone east of the City of Santa Cruz suggests the possibility of late Miocene age sandstone reservoirs in the basin. However, before the 1963 OCS lease sale, drilling in the vicinity was confined to the area east of the San Gregorio fault, except for a 900-foot well drilled by Smuggler-Divide Mining Co. in 1928 (California Division of Oil and Gas, 1983). Since the 1963 sale, two wells were drilled onshore west of the fault. ARCO's "Steele core-hole" No. 1 was spudded in 1963 and reached a depth of 2,675 feet, and in 1968, Ebert and Brandt drilled "Latta" No. 1 to 3,407 feet. Each penetrated post-Miocene sediments overlying rocks of the Pigeon Point Formation of Late Cretaceous age.

Thirteen blocks were offered for leasing in the May 14, 1963, OCS lease sale, but only two attracted bids (appendix 1). A well was drilled on each of the two leased blocks (appendix 3). Both were drilled by Shell Oil Company from the drilling vessel Bluewater II. OCS-P 036 No. 1, located about 13 miles west of Pigeon Point, was spudded in 324 feet of water on February 11, 1967 (fig. 5, col. 5; fig. 9). It was abandoned at a total depth of 9,490 feet on

March 17, 1967. The drill penetrated Quaternary beds to 2,270 feet, the Purisima Formation to 3,520 feet, the Santa Cruz Mudstone to 3,940 feet, the Santa Margarita Sandstone to 3,970 feet, the Monterey Formation to 6,760 feet, the Mindego Formation to 8,500 feet, and the Pigeon Point Formation of Late Cretaceous age to total depth. Drill cuttings throughout the Monterey Formation were coated (up to 100 percent) with free tarry oil, and oil shows were also noted in the Mindego Formation.

OCS-P 035 No. 1, located about 11.5 miles southeast of OCS-P 036 No. 1, was spudded on September 1, 1967, in 328 feet of water and was drilling Pigeon Point Formation when it reached total depth at 7,736 feet (fig. 9). Quaternary beds were penetrated to about 1,630 feet, the Purisima Formation to 1,875 feet, the Santa Cruz Mudstone to 2,015 feet, the Santa Margarita Sandstone to 2,080 feet, the Monterey Formation to 5,730 feet, and the Mindego Formation to 7,210 feet. Although free tarry oil coated the drill cuttings throughout the Monterey Formation, there was somewhat less oil in this well than observed in OCS-P 036. The well was abandoned on September 29, 1967. No formation tests were run on either well.

Hydrocarbon Potential

Observed hydrocarbon source rocks of the Ano Nuevo basin are within the Neogene section. The possibility of Paleogene strata in the basin between the Neogene and

Cretaceous rocks has not been documented. In the OCS-P 036 No. 1 well, the paleontologically "indeterminate" section between 8,500 feet and 9,100 feet could be Paleogene, but has been interpreted in this report to be part of the Pigeon Point Formation of Late Cretaceous age. No indications of hydrocarbon richness were observed within the interval.

The Monterey Formation is a very rich source rock and contains fractured chert reservoir rocks. Cuttings from the interval between 5,800 and 6,700 feet were up to 100 percent coated with free tarry oil, the interval above, up to 4,250 feet, had somewhat less oil, and the interval above that, to 4,050 feet, had cuttings up to 15 percent coated with oil. Oil shows were also noted in the lower Pliocene section above the Monterey Formation. Shows were noted in the sand beds within the Mindego Formation as well. The Mindego Formation is equivalent in age and lithology to the Vaqueros and Rincon Formations, which are, respectively, productive reservoir and possible source beds in the Santa Barbara Channel area. The Mindego Formation contains both source rocks and potential reservoir sandstones. The OCS-P 035 No. 1 well had cuttings with up to 15 percent oil coating throughout the 3,700 feet of Monterey Formation penetrated. Shows were also noted in the upper part of the Mindego Formation.

The presence of excellent hydrocarbon source rocks and potential reservoir rocks in the Ano Nuevo basin is well documented. The observed stratigraphic section in the wells drilled in the basin is notably similar to that drilled in wells in the Point Arguello field in the offshore Santa Maria basin.

Sur Basin

Exploration History

This area was first mapped by oil companies before the 1963 OCS lease sale (Hoskins and Griffiths, 1971). The very narrow shelf and deep water, as well as the relatively thin sedimentary section, suggest limited economic hydrocarbon potential for the basin. No blocks were offered for lease in the 1963 sale due to lack of industry interest; therefore, no wells have been drilled. Additional seismic exploration in the area was performed in preparation for OCS Lease Sales 53 and 73, but the area was not included in either sale.

Hydrocarbon Potential

The Sur basin is expected to have sediments of some of the same formations present in the southern part of the Santa Maria basin. However, the primary target of exploration is the Monterey Formation, which typically varies in lithology laterally as well as vertically. The amount and form of silica are crucial to the fracturability. The highly siliceous beds of Monterey rocks grade laterally into more terrigenous materials with higher clay content, and the diagenetic grade varies from opal A to opal CT and finally to chert. The chert grade rocks are the most brittle and prone to develop reservoir quality fractures. In addition, a depositional thickness sufficient to generate hydrocarbons from organic material in the sediments is required. In the Sur basin, data do not offer any clues pertaining to the quality or distribution of the silica in the Monterey Formation. Observed thickness and pattern of sediments do not indicate a geologic history that would tend to generate commercial volumes of hydrocarbons. However, McCulloch (1982) has reported indications on high resolution, seismic profiles of possible thermogenic gas.

POTENTIAL GEOLOGIC HAZARDS

Geologic hazards are features, conditions, or processes that may, if not prepared for, jeopardize offshore oil and gas exploration and development activities. Most geologic hazards are potential rather than actual and continuous threats. These features pose engineering constraints and can often be effectively mitigated through existing or new technology and design.

Potential geologic hazards in the Central California Planning Area are seismic activity, active faults, mass transport of sediments, hydrocarbons seeps, and shallow gas. Although these features or conditions are discussed separately, they are dynamically interrelated. For example, unconsolidated sediments on a moderate slope have a lowered shear strength due to interstitial shallow gas, and when a nearby active fault slips, the seismic movement may trigger slope failure and mass transport of sediments.

Potential geologic hazards for portions of the Central California Planning Area have been described previously before OCS Lease Sales 53 and 73 (McCulloch and others, 1977, 1980, 1982; McCulloch, 1980; Richmond and others, 1981). Studies related to specific hazards are cited in each section.

Seismicity

Potential hazards attributable to seismic activity include ground shaking, fault rupture, and slope failure. The entire California coast lies within the circum-Pacific volcanic and seismic belt and has been tectonically active throughout middle and late Cenozoic time (fig. 10). Much of the seismic activity along the California coast is due to the interaction between the Pacific and the North American crustal plates. (See discussion on Tectonic and Geologic Setting.) The northward movement of the Pacific plate relative to the North American plate is accommodated as slip along the San Andreas fault zone and subsidiary faults. The relative rate of movement between the two plates is not uniform and is difficult to measure because the area is broken up into blocks by intersecting and branching fault systems. Motion of the North American plate with respect to the Pacific plate is estimated to be 5.5 to 5.8 centimeters per year (Atwater, 1970; Minster and Jordan, 1978; Herd, 1979). Motion along the San Andreas fault in central California is estimated to be between 2.5 and 3.5 centimeters per year (Savage and Burford, 1973; Lindh and others, 1981; McCulloch and others, 1982). The balance of the relative plate motion presumably occurs along other faults of the San Andreas system.

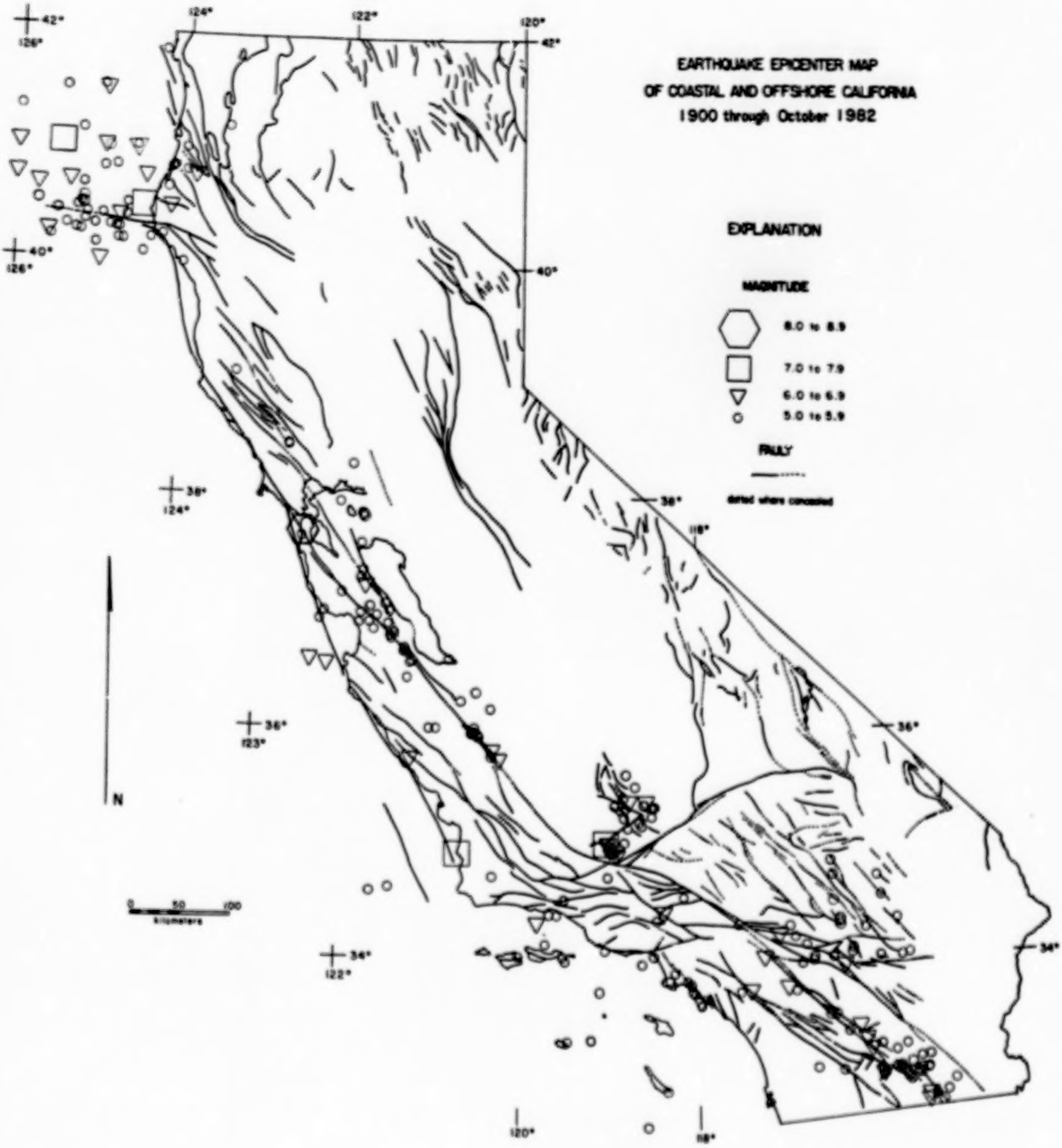

Figure 10. Earthquake epicenter map of coastal and offshore California.

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Offshore basins of the Central California Planning Area lie adjacent to some of the most active faults on the North American continent (figs. 4 and 10). Seismic activity and seismically induced ground motion can be expected in each of these basins. Recent analyses of earthquake strong motion records by Joyner and Boore (1981) have shown not only that accelerations exceeding the force of gravity can accompany large earthquakes, but that these high accelerations persist with little attenuation for several kilometers.

Faults

Numerous faults, trending generally north to northwest, are located offshore and along the coast of central California. Many are active faults that are regarded as potentially disruptive to petroleum exploration and development activities. Faults are considered active where they offset either the seafloor or young sediments (<11,000 years). Faults with historic record of earthquake activity or movement are also considered active. Seismic slip on active faults can result in ground-shaking, seafloor rupture, or slope failure. These potential hazards can be minimized by detailed surveying and analysis before the selection of drill sites and through appropriate engineering practices in the construction and placement of platforms. Faults may also act as conduits along which pressurized, subsurface fluids can reach the surface.

The longest and historically the most destructive strike-slip fault on the North American continent is the San Andreas fault. Within the planning area, the San Andreas forms the eastern borders of the Bodega and La Honda basins and then extends southeasterly along the edge of the onshore La Honda basin about 20 to 25 miles east of the eastern boundary of the Ano Nuevo basin and about 45 miles northeast of the Sur basin (fig. 4). The maximum probable earthquake for the San Andreas fault zone is estimated at magnitude 8.5 (Thenhaus and others, 1980).

The active San Gregorio-Palo Colorado fault zone (fig. 4), part of the San Andreas fault system, forms the eastern boundary of the Ano Nuevo basin. The maximum earthquake magnitude estimated for this fault zone is 6.5 to 7.0 (Greensfelder, 1974). The Seal Cove fault zone, a possible northward extension of the San Gregorio-Palo Colorado fault zone at Half Moon Bay in the west part of the La Honda basin, and the Pilarcitos fault, forming the southeast boundary of the La Honda basin, are both considered potentially active (Cooper, 1973). The San Simeon-Hosgri fault zone, trending northeast along the eastern edge of the Sur basin, is estimated to have a maximum probable earthquake occurrence of magnitude 6.5 to 7.3 (McCulloch and others, 1980). Maximum probable earthquake occurrence is based on historical seismicity of the fault and on estimates of fault rupture length as a percentage of the mapped fault length.

Thenhaus and others (1980) discuss the calculation of maximum probable earthquakes and of probabilistic estimates of maximum seismic horizontal ground motion for coastal California.

In addition to these major active faults, smaller faults, both active and inactive, have been mapped offshore central California (fig. 10). The majority of these faults trend parallel and subparallel to the major faults. These smaller faults may cause concern during offshore oil and gas operations, so they are evaluated on a site specific basis before exploratory or development drilling occurs.

Mass Transport

Mass transport is the downslope movement of unconsolidated to semiconsolidated sediments. Slope failure may occur in response to seismic shaking, overloading or oversteepening of slopes, lowered shear strength of shallow sediments due to interstitial gas, cyclic loading, or combinations of these factors. Gravity-induced slope failure occurs on moderate and steep slopes. However, failures can occur on even gentle slopes. For example, an earthquake on November 8, 1980, beneath Eel River basin offshore northern California, triggered an aerially extensive sediment flow on a slope of 0.25^0 (Field and others, 1980). Failures on gentle slopes probably result from a loss of soil strength due to seismic shaking. Shallow gas often contributes to slope failure by decreasing soil strength. Contrasts in load-bearing capacity may exist within the unstable zone or between the zone and the surrounding sediment. Seafloor instability, whether due to seismic activity or sedimentary processes, is considered the principal constraint to emplacement of bottom-founded structures and pipelines.

Evidence of slope failure is common on the continental shelf and slope off central California. Rubin (McCulloch and others, 1980) has identified areas along most of the continental slope between Vizcaino Knoll, west of Fort Bragg, and Point Reyes in which slumping is occurring or has recently occurred. McCulloch (1982) extends this unstable continental slope south to Monterey Bay. No slumps or slides have been identified on the continental slope west of southern Bodega basin (McCulloch and others, 1977; Richmond and others, 1981).

Shallow slumps and slides, as well as deep-seated lateral displacement of rock masses, have been identified in the northeastern end of Sur basin approximately 5 to 25 miles south of Point Sur (McCulloch, 1980). Large slide blocks of Neogene rocks are underlain and surrounded laterally by zones of contorted bedding. Shallows slumps overlie these blocks, and the seafloor displays characteristic chaotic slump topography. Unmodified slump toes on the seafloor and the absence of ponded young sediments in the topographic depressions indicate that these failures are recent (McCulloch, 1980).

Slump deposits are common in the submarine canyons offshore California. These deposits result from canyon currents undercutting terrace and levee deposits. The intermittent channel fill within the canyons is highly mobile and unstable.

Hydrocarbon Seeps

Hydrocarbon seeps are naturally occurring phenomena that may indicate zones that are potentially hazardous. Seeps offshore central California are generally associated with active faults, shallow over-pressured gas zones, exposed bedrock, or thinly covered bedrock. Seeps may also indicate the location of fractured reservoir rocks.

Water-column anomalies on high resolution geophysical profiles indicate possible hydrocarbon seeps. However, oil and gas seeps emit intermittently, often increasing in response to cyclic loading by waves, storm surges, earthquakes, or tsunamis (Bouma, 1981). Geochemical studies are necessary to document hydrocarbon seeps. Water-column anomalies, indicating possible hydrocarbon seeps, have been identified in Bodega, La Honda, and Ano Nuevo basins (Richmond and others, 1981).

Shallow Gas

Shallow gas in the Central California Planning Area may occur as gas-charged sediment zones or as confined accumulations. Gas-charged sediments are zones of unconsolidated to semiconsolidated sediments saturated with interstitial gas. Decomposition of organic material is the primary source of this biogenic gas. Large contrasts in load-bearing capacity may exist within gas-charged sediment zones and between these zones and the surrounding sediments. Dissolved gas in interstitial pore water can contribute to spontaneous liquefaction when subject to cyclic loading. Interstitial gas can contribute to slope failure by effectively lowering the shear strength of sediments (Sangrey, 1981). Gas-charged sediments appear on high resolution seismic profiles as acoustic anomalies such as acoustically turbid zones, opaque or "wipe-out" zones, or phase changes.

Confined gas accumulations may result from the decay of buried organic matter or from thermogenic gas, originating in deeply buried source rocks, which has migrated upward and become trapped in near-surface sediments. Confined gas accumulations may be under abnormally high pore pressures. This type of shallow gas may also contribute to slope instability by lowering the shear strength of sediments. High-amplitude seismic reflectors or "bright spots" on seismic profiles indicate the possible presence of gas accumulations. Shallow gas accumulations are potentially hazardous if unexpectedly encountered during drilling. Detailed site specific evaluation, suitable drilling programs, adequate casing, and proper mud weights can effectively mitigate the effects of shallow gas.

An extensive gas-charged sediment zone, extending from Horseshoe Point to Bodega Head, has been mapped in northern Bodega basin (McCulloch, 1982). The zone lies along the eastern edge of the basin, shoreward of the 100-meter isobath.

In the Ano Nuevo basin, gas accumulations are evident along the topographic break between the continental shelf and the slope. This shelf-edge gas appears to be migrating up the slope within the unconsolidated sediments (McCulloch and others, 1980; Richmond and others, 1981). The accumulation of the gas at the transition from coarser shelf sediments to finer slope sediments suggests that the gas is biogenic in origin, probably methane (McCulloch, 1982). Gas pits or craters have been identified along the upper edge of the gas zone, indicating possible degassing of the sediments (McCulloch, 1982; Richmond and others, 1981).

Within Sur basin, gas is evident in both Late Tertiary and Quaternary sediments (McCulloch, 1982). From Partington Point to Cape San Martin, continuous and discontinuous zones of shallow gas have accumulated in Quaternary sediments. In an extensive area from Cape San Martin to Point Estero, gas appears to have accumulated in Pliocene strata on the western half of the shelf. On some seismic reflection profiles, the gas can be traced downward to structural highs in the underlying Miocene strata, which are probably the original source of this thermogenic gas (McCulloch, 1982). The seafloor above the gas zone is commonly cratered, probably by escaping gas. Associated failure of surficial sediments occurs in several places.

BIBLIOGRAPHY

Adams, E. W., and Beatty, W. B., 1962, Bituminous rocks in California: California Division of Mines and Geology, Mineral Information Service, April 1962, v. 15, no. 4, p. 12.

Atwater, Tanya, 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, no. 12, p. 3513-3536.

Bachman, S. B., and Crouch, J. K., 1987, Geology and Cenozoic history of the northern California margin: Point Arena to Eel River, *in* Ingersoll, R. V., and Ernst, W. G., eds., Cenozoic basin development of coastal California, Rubey Volume VI: Prentice-Hall, Inc., Englewood Cliffs, N. J., p. 124-145.

Bailey, E. R., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks, and their significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 177 p.

Blake, M. C., Jr., Campbell, R. H., Dibblee, T. W., Jr., Howell, D. G., Nilsen, T. H., Normark, W. R., Vedder, J. G., and Silver, E. A., 1978, Neogene basin formation in relation to plate-tectonic evolution of the San Andreas fault system, California: American Association of Petroleum Geologists Bulletin, v. 62, no. 3 (March 1978), p. 344-372.

Bouma, A. H., 1981, Introduction to offshore geologic hazards, *in* Offshore geologic hazards: American Association of Petroleum Geologists, Education Course Notes Series, no. 18, p. 1-1 to 1-101.

Brabb, E. E., Clark, J. C., and Throckmorton, C. B., 1977, Measured sections of Paleogene rocks from the California Coastal Ranges: U.S. Geological Survey Open-File Report 77-714, 114 p.

Bramlette, M. N., 1946, The Monterey Formation of California and the origin of it siliceous rocks: U.S. Geological Survey Professional Paper 212, 57 p.

California Division of Oil and Gas, 1960, California oil and gas fields--Maps and data sheets, Part 1, San Joaquin--Sacramento Valley and northern coastal regions: California Division of Oil and Gas, p. 3-493.

----- 1969, Supplemental maps and data sheets: California Division of Oil and Gas.

----- 1981, California oil and gas fields, northern California: California Division of Oil and Gas, v. 3.

----- 1982, Regional wildcat map W6-4, Lake, Marin, Mendocino, Solano, Contra Costa, Napa, and Sonoma Counties: California Division of Oil and Gas.

----- 1983, Regional wildcat map W3-10, Alameda, San Mateo, Santa Clara and Santa Cruz Counties: California Division of Oil and Gas.

----- 1987, 72nd Annual report of the State Oil and Gas Supervisor, 1986: California Division of Oil and Gas Publication No. PR06, p. 55-88.

----- 1988, California oil and gas production statistics and new well operations, preliminary report, 1987: California Division of Oil and Gas Publication No. PR03, issued January 1988, p. 11.

Chase, T. E., Wilde, P., Normark, W. R., Miller, C. P., Seekins, B. A., and Young, J. D., 1981, Offshore topography of the western United States between 32^o and 49^o north latitude: U.S. Geological Survey Open-File Map 81-443, scale 1:1,552,146 @ 45^o latitude.

Clark, J. C., 1981, Stratigraphy, paleontology, and geology of the central Santa Cruz Mountains, California Coast Ranges: U.S. Geological Survey Professional Paper 1168.

Clark, J. C., and Brabb, E. E., 1978, Stratigraphic contrasts across the San Gregorio fault, Santa Cruz Mountains, west central California, in Silver, E. A., and Normark, W. R., eds., San Gregorio-Hosgri fault zone, California: Calif. Division of Mines and Geology, Special Report 137, p. 3-12.

Clark, J.C., Brabb, E. E., Greene, H. G., and Ross, D. C., 1984, Geology of the Point Reyes Peninsula and implications for San Gregorio fault history, in Crouch, J. K., and Bachman, S. B., eds., Tectonics and sedimentation along the California margins: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 38, p. 67-86.

Conservation Committee of California Oil Producers, 1986, Annual review of California oil and gas production, 1985: Conservation Committee of California Oil Producers, p. HI-8.

Cooper, Alan, 1973, Structure of the continental shelf west of San Francisco, California: U.S. Geological Survey Open-File Report 73-48, 65 p.

Crandall, R. R., 1943, Halfmoon Bay District, in Geologic formations and economic development of the oil and gas fields of California: Division of Mines Bulletin 118, p. 478-480.

Cummings, J. C., Touring, R. M., and Brabb, E. E., 1962, Geology of the Santa Cruz Mountains, California, in Bowen, O. E., Jr., ed., Geologic guide to the gas and oil fields of northern California: California Division of Mines and Geology Bulletin 181, p. 179-220.

Curray, J. R., 1966, Geologic structure on the continental margin, from subbottom profiles, northern and central California, in Bailey, E. H., ed., Geology of Northern California: Calif. Division of Mines and Geology Bulletin 190, p. 337-342.

Dibblee, T. W., Jr., 1950, Geology of southwestern Santa Barbara County, California; Point Arquello, Lompoc, Point Conception, Los Olivos and Gaviota Quadrangles: California Division of Mines and Geology, Bulletin 150, 95 p.

Field, M. E., Clarke, S. H., Jr., and White, M. E., 1980, Geology and geologic hazards of offshore Eel River basin, northern California continental margin: U.S. Geological Survey Open-File Report 80-1080, 78 p.

Field, M. E., Gardner, J. V., Jennings, A. E., and Edwards, B. B., 1982, Earthquake-induced sediment flows on a 0.25^0 slope, Klamath River Delta, California: Geology, v. 10, p. 542-546.

Fothergill, H. L., 1962, La Honda oil field, in Geologic guide to the gas and oil fields of northern California: California Division of Mines and Geology Bulletin 181, p. 221-223.

Frizzel, V., ed., 1981, Upper Cretaceous and Paleocene turbidites, central California coast: Society of Economic Paleontologists and Mineralogists, Pacific Section Field Trip 6.

Galloway, A. J., 1977, Geology of the Point Reyes Peninsula, Marin County, California: California Division of Mines and Geology Bulletin 202, 72 p.

Gluskoter, H. J., 1969, Geology of a portion of western Marin County, California: California Division of Mines and Geology Map Sheet 11.

Graham, S. A., 1984, Meso-Cenozoic tectonic controls on petroleum occurrence in central California, in Marquez, J., Bell-Countryman, P., and Countryman, R. L., Cenozoic basin development of coastal California: Lecture notes from the Rubey Colloquium, October 3-5, 1984, Department of Earth and Space Sciences, University of California, Los Angeles, p.19-22.

----- 1987, Tectonic controls on petroleum occurrence in central California, in Ingersoll, R. V., and Ernst, W. G., eds., Cenozoic basin development of coastal California, Rubey Volume IV: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, p. 47-63.

Greene, H. G., 1977, Geology of the Monterey Bay region: U.S. Geological Survey Open-File Report 77-718, 340 p.

Greensfelder, R. W., 1974, Maximum credible rock acceleration from earthquakes in California: California Division of Mines and Geology, Map Sheet 23.

Hall, C. A., Jr., Jones, D. L., and Brooks, S. A., 1959, Pigeon Point Formation of Late Cretaceous age, San Mateo County, California: American Association of Petroleum Geologists Bulletin, v. 43, no. 12, p. 2855.

Herd, D. G., 1979, Neotectonic framework of central coastal California and its implications to microzonation of San Francisco Bay region, in Brabb, E. E., ed., Progress on seismic zonation in the San Francisco Bay region: U.S. Geological Survey Circular 807, p. 3-12.

Hopps, Tom, and Horan, Ed, 1983, Subsurface stratigraphy Eel River basin, Humboldt County, California, in Hester, R. L., and Hallinger, D. E., eds., Selected papers of the Pacific Section American Association of Petroleum Geologists annual meeting, Sacramento, California, v. 1, no. 1, May 1983, p. 1-30.

Horn, A. J., 1983, The resurrection of the Half Moon Bay oil field, San Mateo County, California: Pacific Section American Association of Petroleum Geologists 58th Annual Meeting, Sacramento, California, May 19, 1983.

Hoskins, E. G., and Griffiths, J. R., 1971, Hydrocarbon potential of northern and central California offshore, in Cram, I. H., ed., Future petroleum provinces of the United States--their geology and potential: American Association of Petroleum Geologists Memoir 15, v. 1, p. 212-228.

Jennings, C. W., compiler, 1958, San Luis Obispo sheet, Geologic map of California: California Division of Mines, scale 1:250,000.

Jennings, C.W., 1977, Geologic map of California: California Division of Mines and Geology, scale 1:750,000.

Jennings, C. W., and Burnett, J. L., compilers, 1961, San Francisco sheet, Geologic map of California: California Division of Mines, scale 1:250,000.

Jennings, C. W., and Strand, R. G., compilers, 1958, Santa Cruz sheet, Geologic map of California: California Division of Mines, scale 1:250,000.

Joyner, W. B., and Boore, D. M., 1981, Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California, earthquake: Bulletin of Seismological Society of America, v. 71, no. 6, p. 2011-2038.

Keroher, G. C., and others, 1966, Lexicon of geologic names of the United States for 1936-1960, part 3, p-z: U.S. Geological Survey Bulletin 1200.

Koenig, J. B., compiler, 1963, Santa Rosa sheet, Geologic map of California: California Division of Mines and Geology, scale 1:250,000.

Krueger, M. L., 1943, Moody Gulch oil field, in Geologic formations and economic development of the oil and gas fields of California: California Division of Mines and Geology Bulletin 118, p. 477.

Lindh, Allan, Motooka, Carol, Ball, Sandi, and Dollar, Robert, 1981, Current seismicity of the central California coastal region from Point Buchon to Point Piedras Blancas: A preliminary report: U.S. Geological Survey Open-File Report 81-44, 15 p.

McCulloch, D. S., ed., 1980, A summary report of the regional geology, environmental geology, OCS resource appraisal, petroleum potential, and operational considerations in the area of proposed lease sale 73, offshore California: U.S. Geological Survey Open-File Report 80-2007, 132 p.

McCulloch, D. S., 1982, Geohazards on the central California shelf and slope for the northern Santa Maria basin, the Gulf of the Farallones, and the Point Reyes to Rockport Shelf, OCS Lease Sale 73: U.S. Geological Survey Administrative Report, Interagency Agreement AA851-1A1-22, 25 p.

McCulloch, D. S., Clarke, S. H., Jr., Field, M. E., Scott, E. W., and Utter, P. A., 1977, A summary report on the regional geology, petroleum potential, and environmental geology of proposed lease sale 53, central and northern California Outer Continental Shelf: U.S. Geological Survey Open-File Report 77-593, 57 p.

McCulloch, D. S., Clarke, S. H., Jr., Field, M. E., and Utter, P. A., 1982, Regional geology, petroleum geology, and environmental hazards, in Geology, environmental hazards, and petroleum resource potential for 1982 OCS Lease Sale 73, offshore central and northern California: U.S. Geological Survey Open-File Report 82-1000, 77 p.

McCulloch, D. S., Greene, H. G., Heston, K. S., and Rubin, D. M., 1980, A summary report of the geology and geologic hazards in proposed lease sale 53, central California Outer Continental Shelf: U.S. Geological Survey Open-File Report 80-1095, 76 p.

Minerals Management Service, 1983, Pacific OCS Lease Offering, 1963, northern and central California: Department of the Interior, Minerals Management Service, Pacific OCS Region Technical Monograph, 18 p.

----- 1987, Pacific Summary/Index: June 1, 1986 - July 31, 1987: Department of the Interior, Minerals Management Service, OCS Information Report MMS 87-0078, 144 p.

Minster, J. B., and Jordan, T. H., 1978, Present-day plate motions: Journal of Geophysical Research, v. 83, p. 5331-5354.

Mullins, H. T., and Nagel, D. K., 1981, Franciscan-type rocks off Monterey Bay, California: Implications for western boundary of Salinian block: Geo-Marine Letters, v. 1, p. 135-139.

Nilsen, T. H., and Clarke, S. H., Jr., 1975, Sedimentation and tectonics in the early Tertiary continental borderland of central California: U.S. Geological Survey Professional Paper 925.

Ogle, B. A., 1953, Geology of Eel River valley area, Humboldt County, California: California Division of Mines and Geology Bulletin 164, 128 p.

----- 1981, Oil and gas exploration offshore central and northern California: American Association of Petroleum Geologists Circum-Pacific Meeting.

Pemberton, J. R., 1943, Economics of the oil and gas industry of California, in Geologic formations and economic development of the oil and gas fields of California: California Division of Mines and Geology Bulletin 118, p. 4.

Phillips, R. L., 1983, Late Miocene tidal shelf sedimentation Santa Cruz Mountains, California, in Larue, D. K., and Steel, R. J., eds., Cenozoic marine sedimentation, Pacific margin, U.S.A.: Pacific Section Society of Economic Paleontologists and Mineralogists, Los Angeles, California, p. 45-61.

Reed, R. D., and Hollister, J. S., 1936, Structural evolution of southern California: American Association of Petroleum Geologists, 157 p.

Richmond, W. C., Burdick, D. J., Phillips, Diane, and Norris, P. J., 1981, Regional geology, seismicity, and potential geologic hazards and constraints, OCS oil and gas lease sale 53, northern and central California (Sale 53 Part A held May 28, 1981): U.S. Geological Survey Open-File Report 81-318, 36 p.

Rintoul, Bill, 1987, California offshore update: Pacific Oil World, v. 79, April 1987, p. 4-9.

Risotto, S. P., and Rudolph, R. W., 1936, Pacific Summary Report/Index, November 1984 - May 1986: Department of the Interior, Minerals Management Service OCS Information Report MMS 86-0060, 115 p.

Rogers, T. H., compiler, 1966, San Jose sheet, Geologic map of California: California Division of Mines and Geology, scale 1:250,000.

Sangrey, D. A., 1981, Geotechnical engineering link between offshore processes and hazards, in Offshore geologic hazards: American Association of Petroleum Geologists, Education Course Notes Series, No. 18, p. 3-1 to 3-75.

Savage, J. C., and Burford, R. O., 1973, Geodetic determination of relative plate motion in central California: Journal of Geophysical Research, v. 78, no. 5, p. 832-845.

Silver, E. A., Curray, J. R., and Cooper, A. K., 1971, Tectonic development of the continental margin off central California, in Lipps, J. H., and Moores, E. M., eds., Geologic guide to the northern coastal ranges, Point Reyes region, California, Geological Society of Sacramento, Annual Field Trip Guide Book.

Stalder, Walter, 1943, History of exploration and development of gas and oil in northern California, in Geologic formations and economic development of the oil and gas fields of California: Division of Mines Bulletin 118, p. 75-80.

Stanley, R. G., 1985, Middle Tertiary sedimentation and tectonics of the La Honda basin, central California: U.S. Geological Survey Open-File Report 85-596.

Thenhaus, P. C., Perkins, D. M., Ziony, J. I., and Algermissen, S. T., 1980, Probalistic estimates of maximum seismic horizontal ground motion on rock in coastal California and adjacent Outer Continental Shelf: U.S. Geological Survey Open-File Report 80-924, 69 p.

Turner, D. L., 1970, Potassium-argon dating of Pacific coast Miocene foraminiferal stages, in Bandy, O. L., ed., Radiometric dating and paleontologic zonation: Geological Society of America, Special Paper 124, p. 91-129.

Tyler, J. H., 1972, Pigeon Point Formation and Upper Cretaceous shoreline succession, central California coast: Journal of Sedimentary Petrology, v. 42, no. 3.

Underwood, M. B., 1985, Sedimentology and hydrocarbon potential of Yaeger structural complex--possible Paleogene source rocks in Eel River basin, northern California: American Association of Petroleum Geologists, v. 69, no. 7, p. 1088-1100.

U.S. Bureau of Land Management, 1976a, OCS Protraction Diagram NJ 10-4 Navarro Canyon, scale 1:250,000.

----- 1976b, OCS Protraction Diagram NJ 10-5 Santa Rosa, scale 1:250,000.

----- 1976c, OCS Protraction Diagram NJ 10-8 San Francisco, scale 1:250,000.

----- 1976d, OCS Protraction Diagram NJ 10-11 Santa Cruz, scale 1:250,000.

----- 1976e, OCS Protraction Diagram NJ 10-12 Monterey Bay, scale 1:250,000.

----- 1976f, OCS Protraction Diagram NI 10-2 (No Name), scale 1:250,000.

----- 1983, OCS Protraction Diagram NI 10-3 San Luis Obispo, scale 1:250,000.

U.S. National Ocean Survey, 1974a, Bathymetric map, Point Reyes to Tolo Bank, California, NOS 1307N-18B: U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, scale 1:250,000.

----- 1974b, Bathymetric map, vicinity Point Sur to Point Reyes, California NOS 1307N-11B: U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, scale 1:250,000.

----- 1975, Bathymetric map, Cape San Martin to Point Conception, NOS 1306N-20: U.S. Department of Commerce, National Oceanographic and Atmospheric Administration, scale 1:250,000 (with BLM protraction diagram over prints for OCS Resource Management Map NI 10-3, NI 10-6, and Map 6A).

Weaver, C. E., 1943, Point Arena-Fort Ross region, in Geologic formations and economic development of the oil and gas fields of California: California Division of Mines Bulletin 118, April 1943, p. 628-632.

----- 1944, Geology of the Cretaceous (Gualala Group) and Tertiary formations along the Pacific coast between Point Arena and Fort Ross, California: University of Washington Press, v. 6, no. 1, p. 1-29.

----- 1949a, Geology and minerals deposits of an area north of San Francisco Bay, California: California Division of Mines Bulletin 149, September 1949.

----- 1949b, Geology of the Coast Ranges immediately north of the San Francisco Bay region, California: Geological Society of America Memoir 35, October 20, 1949, p. 65.

Weber, G. E., and La Joie, K. R., 1979, Evidence for Holocene movement on the Frijoles fault near Point Ano Nuevo, San Mateo County, California, in Weber, G. E., and others, eds., Coastal tectonics and geologic hazards in Santa Cruz and San Mateo counties, California: Geologic Society of America, Cordilleran Section, 75th Annual Meeting.

Webster, F. L., Burdick, D. J., Griggs, D. G., and Yenne, K. A., 1985, Geologic report, proposed Southern California Planning Area, OCS Lease Sale No. 95: U.S. Department of the Interior, Minerals Management Service OCS Report MMS 85-0042.

Webster, F. L., Burdick, D. J., and Yenne, K. A., 1986, Geologic report, proposed Northern California Planning Area, OCS lease sale no. 91: U.S. Department of the Interior, Minerals Management Service OCS Report MMS 86-0025.

Webster, F. L., and Yenne, K. A., 1987, Pacific OCS lease sale of May 14, 1963, northern and central California: U.S. Department of the Interior, Minerals Management Service OCS Report MMS 87-0108, October 1987.

Wentworth, C. M., Jr., 1966, The Upper Cretaceous and lower Tertiary rocks of the Gualala area, northern Coast Ranges, California: Stanford University, Palo Alto, California, unpublished Ph.D. dissertation.

Whelan, Thomas, III, Coleman, J. M., Suhayda, J. N., and Roberts, H. A., 1978, Acoustical penetration and shear strength in gas-charged sediments: Marine Geotechnology, v. 2, p. 147-159.

Wilde, P., 1978, Channel sands and petroleum potential of Monterey deep-sea fan, California: American Association of Petroleum Geologists Bulletin, v. 62, no. 6, p. 967-983.

Wilde, P., Normark, W. R., and Chase, T. E., 1976, Petroleum potential of the continental rise off central California, in Halbouty, M. R., Maher, J. C., and Lian, H. M., eds., Circum-Pacific energy and minerals resources: American Association of Petroleum Geologists Memoir 25, p. 313-317.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States (including Alaska): U.S. Geological Survey Bulletin 896.

Zieglar, D. L., and Cassell, J. K., 1978, A synthesis of OCS well information, offshore central and northern California, Oregon, and Washington: Paper presented at 53rd Annual Meeting, Pacific Section, American Association of Petroleum Geologists, Sacramento, California, April 28-29, 1978, 27 p.

APPENDIX 1. Summary Information for the Central California Planning Area Portion of the Pacific OCS Lease Sale of May 14, 1963

OCS-P No.	Block No.	Bidder	Acreage	Bid Per Acre	Total Bid	Relinquished Date
024	15N 23W	Shell Oil Co.	2237.43	$ 28.30	$ 63,335.40	06/14/67
025	16N 23W	Shell Oil Co.	5760	28.01	161,337.60	06/14/67
026	15N 24W	Shell Oil Co.	2327.42	11.76	27,377.28	06/14/67
027	16N 24W	Shell Oil Co.	5760	36.72	211,507.20	06/14/67
028	17N 24W	Shell Oil Co.	5760	11.52	66,355.20	06/14/67
035	15N 37W	Shell Oil Co.	5760	14.10	81,216.00	06/14/68
036	18N 40W	Shell Oil Co.	5760	14.10	81,216.00	06/14/68
037*	33N 45W***	Shell Oil Co.	5760	11.52	66,355.20	06/14/67
038*	34N 45W**	Shell Oil Co.	4310	12.27	52,883.70	06/14/67
039*	34N 46W**	Shell Oil Co.	4320	36.72	158,630.40	06/14/67
		Humble/Std. Cal.		18.17	78,494.40	
040*	34N 47W**	Shell Oil Co.	5450	57.11	311,249.50	06/14/67
		Humble/Std. Cal.		14.43	78,643.50	
041*	35N 47W**	Shell Oil Co.	700	454.80	318,360.00	05/22/67
		Humble/Std. Cal.		179.17	125,419.00	
042*	34N 48W	Shell Oil Co.	5760	14.10	81,216.00	06/14/67
043*	35N 48W**	Shell Oil Co.	5680	416.00	2,362,880.00	05/22/67
		Humble/Std. Cal.		70.83	402,314.40	
		Superior Oil Co.		8.15	46,292.00	
044*	36N 48W**	Shell Oil Co.	5680	11.52	65,433.60	06/14/67
		Humble/Std. Cal.		10.77	61,173.60	

APPENDIX 1. Summary Information for the Central California Planning Area Portion of the Pacific OCS Lease Sale of May 14, 1963--continued

OCS-P No.	Block No.	Bidder	Acreage	Bid Per Acre	Total Bid	Relinquished Date
045*	36N 49W***	Shell Oil Co.	5760	11.52	66,355.20	06/14/67
046*	37N 49W	Shell Oil Co.	5760	14.10	81,216.00	06/14/67
047*	38N 49W	Shell Oil Co.	5760	8.85	50,976.00	06/14/67
048*	39N 49W	Shell Oil Co.	5760	8.85	50,976.00	06/14/67
049*	40N 49W	Shell Oil Co.	5760	8.85	50,976.00	06/14/67
050*	41N 49W	Shell Oil Co.	5760	14.10	81,216.00	06/14/67
051*	37N 50W	Shell Oil Co.	5760	153.00	881,280.00	06/14/67
052*	38N 50W	Shell Oil Co.	5760	36.72	211,507.20	06/14/67
053*	41N 50W	Shell Oil Co. Humble/Std. Cal	5760	28.30 6.02	163,008.00 34,675.20	06/14/67
054*	42N 50W	Shell Oil Co.	5760	8.85	50,976.00	06/14/67
055*	40N 51W	Shell Oil Co.	5760	111.65	643,104.00	06/14/67
056*	41N 51W	Shell Oil Co.	5760	27.76	159,897.60	06/14/67
057*	40N 52W***	Shell Oil Co.	5760	14.10	81,216.00	06/14/67
058*	41N 52W***	Shell Oil Co.	5760	11.52	66,355.20	06/14/67

* These leases carry the stipulation concerning the Point Reyes National Seashore Area.

** All that portion lying seaward of a line 3 geographical miles distant from the coast line of California.

*** No drilling or production activities will be allowed on S 1/2 OCS-P 037, W 1/2 OCS-P 045, W 1/2 OCS-P 057, and W 1/2 OCS-P 058.

APPENDIX 2. La Honda Basin (Onshore) Production Data

Field	Year of Discovery	Hydrocarbon	Cumulative Through 1986[1]	1987 Production[2]	Cumulative Through 1987	Estimated Ultimate Production[1]
Half Moon Bay	1867	Liquid	54,000 bbl	1,700 bbl	55,700 bbl	<154,000 bbl
		Gas	23,000 Mcf	450 Mcf	23,450 Mcf	35,000 Mcf
Moody Gulch	1878[3]	Liquid	98,000 bbl	----	98,000 bbl	----
		Gas	44,000 Mcf	----	44,000 Mcf	----
Oil Creek	1955	Liquid	197,000 bbl	5,300 bbl	202,300 bbl	<297,000 bbl
		Gas	77,000 Mcf	500 Mcf	77,500 Mcf	< 87,000 Mcf
La Honda	1956	Liquid	1,325,000 bbl	9,900 bbl	1,334,900 bbl	<1,425,000 bbl
		Gas	150,000 Mcf	0 Mcf	150,000 Mcf	172,000 Mcf

References:

[1] California Division of Oil and Gas, 1987.

[2] California Division of Oil and Gas, 1988.

[3] California Division of Oil and Gas, 1981.

APPENDIX 3. Summary of Central California Planning Area OCS Exploratory Wells

Operator	Lease	Well No.	API No.	Location Lat./Long	Vessel	Spud Date	Completion Date	Water Depth (feet)	Total Depth (feet)	Rotary Table Elevation (feet)
Shell	P-027	1	56-069-00004	38°20.5'N. 123°17.2'W.	Bluewater II	11-17-64	11-29-64	348	3,234	70
Shell	P-035	1	56-068-00001	37°06.8'N. 122°29.9'W.	Bluewater II	09-01-67	09-29-67	328	7,736	68
Shell	P-036	1	56-068-00002	37°14.1'N. 122°38.9'W.	Bluewater II	02-11-67	03-17-67	324	9,490	68
Shell	P-039	1	56-068-00003	37°56.3'N. 122°59.1'W.	Bluewater II	02-16-65	03-03-65	200	5,632	69
Shell	P-041	1	56-068-00005	37°57.7'N. 123°04.9'W.	Glomar II	09-20-63	12-13-63	250	4,700	30
Shell	P-051	1	56-069-00006	38°04.3'N. 123°13.6'W.	Glomar II	12-22-63	01-10-64	368	1,170	30
Shell	P-051	2	56-069-00007	38°04.3'N. 123°13.6'W.	Bluewater II	08-02-64	10-03-64	363	10,466	70
Shell	P-053	1	56-069-00008	38°12.9'N. 123°14.6'W.	Bluewater II	12-02-64	12-26-64	346	8,059	70
Shell	P-055	1	56-069-00009	38°11.4'N. 123°18.1'W.	Bluewater II	10-12-64	11-06-64	414	7,477	68
Shell	P-055	2	56-069-00010	38°10.4'N. 123°18.0'W.	Bluewater II	01-03-65	01-23-65	421	7,261	68
Shell	P-055	2A	56-069-00011	38°10.4'N. 123°18.0'W.	Bluewater II	01-24-65	02-03-65	421	7,297	68
Shell	P-058	1	56-069-00012	38°12.9'N. 123°19.7'W.	Bluewater II	01-18-67	02-05-67	440	7,881	68

GLOSSARY

Abyssal plain - nearly flat area of the ocean floor occupying the deepest part of the ocean basin seaward of the continental margin.

Anoxic - without chemically available oxygen.

API gravity - a standard adopted by the American Petroleum Institute for denoting the density of crude oil, in which the lower the specific gravity, the higher the API gravity.

Basement rocks - rocks lying beneath dominantly sedimentary rocks. Basement rocks are characteristically dense and hard with very poor porosity and permeability.

Basin - a depression of the Earth's crust in which sedimentary materials accumulate or have accumulated, usually characterized by continuous sediment deposition over a long period of time.

Biogenic gas - gas formed in sediments at shallow depths by decay of organic material through bacterial action.

Bioturbated - sediments that have been churned and stirred by burrowing organisms.

Bleeding oil - crude oil seeping from rock pores. An expression commonly used to describe rock cores.

California Coordinate System (Lambert) - a base map system in which the offshore area is divided into blocks that are 3 miles on each side and that encompass 5,760 acres.

Chert - a very dense, hard sedimentary rock consisting of microscopically crystalline silica.

Coeval - of the same or equal age or duration.

Continental margin - the ocean floor between the shoreline and the abyssal plain. Consists of the continental shelf, continental slope, and continental rise.

Continental rise - the gently inclined portion of the continental margin, between the base of the continental slope and the abyssal plain.

Continental shelf - the shallow, gently inclined portion of the continental margin adjacent to the shoreline. Terminated seaward by a relatively sharp break in slope called the shelf break, or at 200 meters if there is no discernible change in slope.

Continental slope - the part of the continental margin that is between the continental shelf and the continental rise. Characterized by its relatively steep slope of 3-6^0.

Crustal plate - a rigid segment of the Earth's lithosphere (crust) that moves horizontally and adjoins other crustal plates along zones of seismic activity, according to the theory of plate tectonics.

Cut - visible oil from well cuttings dissolved in a solvent.

Dead oil - solid petroleum that contains no liquid or gaseous fractions.

Deep-sea fan - a fan-shaped accumulation of sediments located seaward of large rivers and submarine canyons, generally in water depths exceeding 2,000 meters. Also called a submarine fan.

Depositional cycle - a sequence of sedimentary strata that are arranged in an orderly and predictable manner and that are repeated in the same order; usually sediments deposited by a transgressing sea, followed by sediments deposited by a regressing sea.

Diagenetic change - the physical and chemical changes that occur in sediments following deposition that convert the sediments to consolidated rock.

Discovery - the initial find of significant quantities of fluid hydrocarbons on a given field.

Drill cuttings - rock fragments cut by the drill bit. Also called well cuttings.

Drill stem test (DST) - a test of the productive capacity of a well while the drill hole is still full of drilling mud. The test tool is attached to the drilling pipe.

Earthquake epicenter - the point on the Earth's surface directly above the location (focus) of an earthquake.

En echelon - said of geologic features that are in an overlapping or staggered arrangement.

Exclusive Economic Zone (EEZ) - the maritime region extending 200 nautical miles from the shoreline in which the United States has exclusive rights and jurisdiction over living and nonliving resources.

Fluorescence - emission of visible light from oil that has been exposed to ultraviolet light.

Formation - a bed or deposit sufficiently homogeneous to be distinctive as a unit; the basic mappable unit in the classification of rocks.

Fracture reservoir - a reservoir whose permeability depends on the breaking or shattering of an otherwise less pervious rock.

Franciscan assemblage - heterogeneous mixture of sedimentary and volcanic rocks that have been deposited exclusively in deep basins on oceanic crust and whose age varies from Late Jurassic to Early Cretaceous; a subduction complex. Also the Franciscan Melange.

Heavy oil - oil with gravity less than 20° API.

Hiatus - a break or interruption in the continuity of the geologic record due to nondeposition or erosion.

Hydrocarbon potential - the potential of an area to contain hydrocabon accumulations; incorporates factors including the likely existence of adequate source rocks, reservoir rocks, traps, seals, maturation, migration, and timing.

Hydrocarbons - a large class of organic compounds containing primarily carbon and hydrogen, which may be in gaseous, liquid, or solid form. Includes crude oil and natural gas.

Marine regression - the retreat of the sea from land areas.

Marine transgression - the spread of the sea over land areas.

Metasediment - sediments or sedimentary rocks that show evidence of metamorphism.

Orogenic/depositional cycle - a cycle in which subsidence and deposition is followed by uplift and erosion.

Outer Continental Shelf (OCS) - all submerged lands under Federal jurisdiction that compose the continental margin seaward of the State offshore lands (i.e., seaward of the 3-mile line).

Permeability - the measure of the ease with which fluids may move through the interconnected pores of a rock; the measure of a rock's ability to transmit fluids.

Physiography - a description of the surface features of the Earth.

Porosity - the pore or void space in the rock, expressed as a percentage of the total volume of the rock.

Reservoir rock - porous and permeable rock in which hydrocarbons can accumulate and from which they can be recovered.

Salinian block - named for the granitic "backbone" of the Salinas Valley; thought to be a land mass from Late Jurassic to possibly early Miocene time.

Seismicity - the phenomenon of Earth movements.

Show - indication of the presence of hydrocarbons in a well, detected in a core, cuttings, or circulating drilling fluid, or from electrical or geophysical logs run in the well.

Silica diagenesis - phase transformations of biogenic silica first to meta- stable opal and then to quartz.

Siliceous - containing abundant silica.

Sour oil or gas - oil or gas containing a significant fraction of sulfur compounds, notably hydrogen sulfide.

Source rock - sedimentary rock with high organic content capable of generating hydrocarbons in response to pressure and heat.

Spud - to begin drilling a well.

Stratigraphy - the geologic study of the distribution, chronologic succession, correlation, and mutual relationships of rock strata.

Sweet oil or gas - oil or gas containing very little sulfur of sulfur compounds.

Tectonics - a branch of geology dealing with processes affecting the broad architecture of the upper part of the Earth's crust (e.g., mountain building, basin subsidence, uplift, compressional folding).

Thermogenic gas - gas formed from organic material by heat and pressure at depths within the earth.

Topography - the general configuration of a land surface, including its relief and the position of its natural and manmade features.

Trap - a geologic configuration that permits the accumulation and prevents the escape of hydrocarbons from reservoir rocks.

Truncate - to cut or break off the top or end of a geologic structiture, as by erosion.

Turbidite - a sediment deposited by gravity currents in the ocean.

Unconformity - a substantial gap in the geologic record where a rock unit is overlain by another that does not normally follow in stratigraphic succession.

Unconsolidated - a sediment whose particles are not cemented together.

Universal Transverse Mercator (UTM) - a base map system in which the offshore is divided into blocks that are 4,800 meters on each side and that encompass 2,304 hectares.

Uplift - a structurally high area in the crust, produced by movements that raised the rocks.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

March 3 1849

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